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United States
Department of
Agriculture

Forest Service

Forest Pest
Management

Davis, CA

FOURTH REPORT

NATIONAL SPRAY MODEL STEERING COMMITTEE

FPM 93-16
September 1993

United States
Department of
Agriculture

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Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

FPM 93-16
September 1993

Fourth Report

National Spray Model Steering Committee

Prepared by:

John W. Barry
Chairperson

USDA Forest Service
Forest Pest Management
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FOURTH REPORT

National Spray Model Steering Committee

A Report of the Spokane, WA
Meeting - June 23-24, 1993

23 September 1993

USDA Forest Service
Washington Office/Forest Pest Management
2121 C 2nd Street
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CONTENTS

I. INTRODUCTION

The meeting was held at the Spokane Convention Center, Spokane, WA, June 23-24, 1993 in conjunction with the International Summer Meeting of the American Society of Agricultural Engineers (ASAE). This scheduling provided for economies in travel as several members also had planned to attend the ASAE meeting.

A. Attendees

Jack Barry	USDA, Forest Service FPM	2121-C 2nd Street Davis, CA 95616 (916)758-4600
Terry L. Biery	USAFR	910 AG/DOS 3976 King Graves Rd. Youngstown-Warren Rgn-Arpt ARS, OH 44473-0910 (216)392-1178/1111
Temple Bowen	NOVO NORDISK	33 Turner Rd. Danbury, CT 06813-1907 (203)790-2632
Baozhong Duan	Penn State Univ	Pesticide Research Lab University Park, PA 16802 (814)865-3770
Robert Ekblad	USFS (Retired)	P.O. Box 161 Dayton, MT 59914 (406)549-3996
J. D. Fish	RHONE-POULENC	2551 NC 42 EAST Clayton, North Carolina 27520 (919)553-4654
Harold Flake	USDA Forest Service	1720 Peachtree Rd, NW Atlanta, GA 30367 (404)347-2961

Bruce Grim	Dugway Proving Ground	JCP Dugway Proving Ground Dugway, Utah 84022 (801)831-3371
Ellis Huddleston	New Mexico State Univ	Box 3BE Las Cruces, NM 88003 (505)646-3934
Bob Mickle	Environment Canada	4905 Dufferin Street Downsview, Ontario, Canada M3H 5T4 (416)739-4851
Karl Mierzejewski	Penn State Univ	Pesticide Research Lab University Park, PA 16802 (814)865-1021
Dave Miller	Univ of Connecticut	308 W.B. Young Building 1376 Storrs Road Storrs, CT 06268 (203)486-2840
James E. Rafferty	Dugway Proving Ground	MT-M Dugway Proving Ground Dugway, Utah 84022 (801)831-5101
John Ray	NZ Forest Research Institute	Private Bag 3020 Rotorua, New Zealand 82179 0116473-475516
David W. Rising	Missoula Tech & Dev Center	Bldg #1 Ft. Missoula Missoula, MT 59801 (406)329-3904
Bob Sanderson	New Mexico State University	Box 3BE NMSU Las Cruces, NM (505)646-3543
Pat Skyler	USDA, Forest Service FPM	2121-C 2nd Street Davis, CA 95616 (916)758-4600
William E. Steinke	Univ of CA	Bio & Ag Engineering Davis, CA 95616 (916)752-1613

Milton Teske	Continuum Dynamics, Inc.	P.O. Box 3073 Princeton, NJ 08543 (609)734-9282
Harold Thistle	Missoula Tech & Dev Center	Bldg #1 Ft. Missoula Missoula, MT 59801 (406)329-3981
Dave Valcore	DOW/Elanco	9550 Zionsville Rd S. Campus Bldg. 304 Indianapolis, IN 46268 (317)873-7886
Joel T. Walker	Univ of Arkansas	203 Engineering Hall Bio & Ag Engineering Fayetteville, AR 72701 (501)575-2351
C. David Whiteman	Battelle NW Labs	P.O. Box 999 Richland, WA 99352 (509)376-7859
Alvin R. Womac	Univ of Tennessee	Agr Engr Dept P.O. Box 1071 Knoxville, TN 37901-1071 (615)974-7266

B. Purpose of Committee/Meeting

The purpose of the committee is:

1. To coordinate national & international spray model R&D;

2. To facilitate cooperation, partnerships, and economies;

3. To maintain a 5-year tactical plan of goals, objectives and planned actions;

4. To identify model & application technology needs; and

5. To support the advancement of technology for the safe, economic, efficacious application of biorational and other pesticides.

The purpose of the meeting was:

1. To share information on development activities among the members;

2. To encourage formation of partnerships; and

3. To identify spray model and pesticide application technology development needs.

II. DISCUSSION

The discussion as presented herein is a summary of remarks by attendees and/or a summary of their work. Some attendees provided a written summary which is enclosed in the Appendices.

A. Attendees Remarks and Reports

<u>Dave Valcore</u>

- SDTF is actively pursuing a spray model to satisfy EPA pesticide label requirements.
- Need to settle on a standard set of collectors.
- Glossary of terms related to spray drift and application technology will be prepared by EPA-ERL and published as a peer reviewed article.
- SDTF is not addressing needs of disease vector control program.

<u>Milt Teske</u>

- FSCBG version 4.3 will require a 486 computer in some extended application. The reason is importance of inputting all nozzles and up to 100 drop size classes for accurate downwind predictions.
- A detailed report by Milt is in the appendix.

<u>John Ray</u>

- Reported on Forest Research Institute, New Zealand, field evaluation of FSCBG model. FRI was pleased with how well predictions compared to observed data.
- Need expert system interface with FSCBG.
- Interested in orchard sprayer and shelter belt drift management.
- Need to evaluate and validate LICOR system.

Bob Mickle

- Plans to use spray models to determine size of buffer zones surrounding pesticide treatment areas.
- Plans to use spray model in the pesticide registration process.
- Canada is presenting an advanced international course on forest-use pesticides, September 27-October 8, 1993 at University of Guelph, Guelph, Ontario.
- Has reported on field results that suggest spray aircraft characterization trials should be done under cross-wind in lieu of in-wind conditions.
- Is proposing joint work on an interactive GPS airborne system with FSCBG.
- Reported that spray from right side of aircraft behaves differently from that on left side.
- Milt's sensitivity data should be in "FSCBG HINT BOOK."

Dave Miller

- Will take a sabbatical to White Sands Missile Range to analyze Program Wind data.
- Prepared a 5-Year Plan for forest canopy characterization and micrometeorology to support the FSCBG model.
- Suggested need for a bibliography on collector efficiency.
- Conducted canopy trials in Pennsylvania using LIDAR from Los Alamos to track spray cloud movement above forest canopy.
- Working with Pennsylvania State on leaf area index for hardwood forests.

Karl Mierzejewski

- Suggested organizing a seminar on sampling - types, efficiency, and evaluation.

- SDTF, Penn State, and FPMI are involved to some degree in comparing spray deposition and air samplers.

- Using AGDISP model.

Ellis Huddleston

- Reminded group about ASTM, Ft. Worth meeting, October 12-15, 1993.

- Members are invited to do testing at Las Cruces.

- Working on effects of adjuvants on atomization and drift.

- Using string as a drift sampler - but Teflon string is a problem. String gives a vertical slice of the drift cloud.

Bob Sanderson

- Need an "FSCBG Hint Book" to support FSCBG that includes vertical downwind flux. (Bob, please provide write-up on this so the committee understands what you are proposing.)

- Cooperating with FS and Texas FS on development of an aerial spray simulator.

Baozhong Duan

- Working on Dimilin persistence studies.

- Studying adjuvants and aircraft release heights.

Bill Steinke

- Completed an evaluation of field trial data conducted by the Forest Service. One objective of the trials was to demonstrate that deposit cards should be positioned flat at ground level for consistent recoveries when doing aircraft characterization trials.

- Limit for PMS detection is 28 um and larger. Although very little mass is contained in drops below 28 um, there are large numbers of drops which may be of concern in drift situations.

- Continuing to evaluate atomization using 3 dimensional analysis to determine theoretical drop size distribution.

- Working in orchards using ground spray application.

- Involved in seeding orchards with parasitized eggs.

- Working on aerosols in greenhouses with focus on worker exposure - involves GLP and PMS.

- Proposes to have a symposium after or before next ASAE meeting - Purpose: There is technology and knowledge in this group that can be given to ground application people. Possibly set up rap session at ASAE winter meeting.

- Has a database on air blast sprayers which might be useful to Milt Teske, Harold Thistle, and John Ray.

Terry Biery

- Aerial spraying with C-130 E - 2,000 gallon tank, 200 KTS, and 1/2 mile swath width.

- Model needs -

    - Have model accommodate more nozzles.

    - Validate model for spray flux (How much product passes through a given space in a certain period of time).

    - Develop a simplified version to use on-site to make spray go/no-go decisions.

- Working with USDA-ARS on dispersing material to control oil spills. Application rate is 5 gallons per acre. Oil sensitive cards have been working well for droplet-size determinations.

- Used FSCBG to plan aerial spraying strategies for Desert Storm.
- USAFR will be conducting their pesticide course October 18-22 at Youngstown, Ohio.
- Did aerial spraying of 0.25 million acres to control saltmarsh mosquitoes after Hurricane Andrew.

Jim Rafferty

- Announced that Keith Dumbauld, who was the lead scientist in developing FSCBG, died earlier this year. For those who knew Keith he will be remembered as a dedicated scientist committed to high standards and productivity.
- Has been evaluating canopy and drift data.
- Suggests we investigate utility of the US Army volume (vs line) source model.

Harold Thistle

- Southern Research Institute has completed droplet evaporation studies for the FS and SDTF. A report will be issued soon.
- Will be conducting ground sprayer tests.
- Will prepare a user manual for VALDRIFT model in cooperation with model developers at Battelle.
- Interested in producing publications to help field users.

Harold Flake

- Using FSCBG operationally in the Southeast for aerial application in seed orchards and gypsy moth control.
- GPS needs to be incorporated into FSCBG for spray placement. Thirty percent of treatment costs are spent to mark block boundaries, so plan to evaluate GPS unit for marking.
- Plans to do CASPR model validations.

Bob Ekblad

- Need a seminar on orchard air blast sprayer use and technology.
- Should share model technology with ground application users.
- Impressed with level of model advancement and technology transfer.

Bruce Grim

- Coordinate spray drift and non-target impact study in Utah to support gypsy moth project.
- Has 3 years of canopy penetration data in Gamble oak and big-leaf maple.
- Need vertical profile data in mountain canyons to describe spray drift and behavior.

Dave Rising

- MTDC is working on first year of the MTDC/FPM 5-Year Program.
- Need to pool the vast Forest Service professional knowledge for project needs.

Dave Whiteman

- New developments with the Global Positioning System (GPS) and with lidar should be followed by the committee to see that these new technologies are used in the future to support spray modeling and spray operations. The GPS could greatly improve our ability to determine the actual locations of spraying and thus improve the "source term" in our model calculations. The lidar could be used to help us understand near-aircraft spray dispersion and could be used to improve the AGDISP model.
- A Rule of Thumb manual on complex terrain meteorology and its effects on spray dispersion should be produced.
- We should continue to monitor developments in full-physics atmospheric numerical modeling, as such models may become suitable for operational or applications use in the near future.
- We should continue to monitor research regarding the coupling and decoupling of valley and above-valley flows, as this is a key

unresolved factor in our spraying operations in complex terrain areas.

- We should continue our efforts to evaluate present models using actual spray trials.

- A grid-based topography model should be developed to predict the propagation of shadows across regions of complex terrain after sunrise and the related development of convective boundary layers. Such a model could be used to help plan spray operations so that spraying could continue after convective boundary layers become too deep and winds too strong over the slopes that face most directly into the sun. The Forest Service has equipment and techniques that could be applied to develop such a model.

- Will be writing journal articles in next year on VALDRIFT model.

Jack Barry

- Dugway library has a tome on sampler and collector efficiency work done in the 1940's by Department of War. The country's top scientists were working on this for defense against chemical and biological agents.

- There is an extensive database on canopy meteorology in the Program WIND database. This needs to be retrieved for FSCBG model verification studies.

B. Sub-Committee on Meteorology

The committee, under Dave Whiteman as chairperson, developed an outline of steps to be taken to acquire meteorological data for evaluating and operationally using the model. (See Appendix B - Dave Whiteman).

C. Sub-Committee on Models in the Regulatory Process

This report was delivered by Dave Valcore for Dave Esterly, chairperson. (See Appendix B - Dave Valcore).

D. Needs

A round table discussion of FSCBG and application technology needs were identified as follows:

1. Characterize the spray pattern and droplet spectrum of air blast orchard sprayers in open terrain and orchards (deciduous and coniferous).

2. Link GPS on-board aircraft system interactively to FSCBG for real-time decision making and real-time tracking accounting, and documentation. Provide for direct data input to FSCBG from Aircraft Spray Monitors with FSCBG being capable of modeling each spray line separately and then summing results.

3. Evaluate significance of aircraft vortex decay as function of right/left side of aircraft. Assess the lifetimes of the two vortices in cross wind scenarios so that an empirical relationship can be developed to modify the destruction of the vortices used in FSCBG. Recent studies have shown that there is sufficient difference in the lifetimes of the two vortices when spraying in cross winds to significantly influence the deposit/drift from the two wings.

4. Evaluate with existing data the time/distance "handshake" between AGDISP to FSCBG and evaluate need for field tests.

5. Conduct field tests to evaluate potential of trees or shelter belts to reduce spray drift from forest and agricultural crops.

6. Prepare a "HINT BOOK" for FSCBG to include FSCBG sensitivity parameters. The book should indicate the accuracy to which the various input parameters must be measured in order to be able to attempt a comparison between field and model results.

7. Modify FSCBG for buffer zone calculations.

8. Develop strategies to transfer FSCBG technology to aerial applicators and the agricultural community.

9. Standardize spray drift sampling methods, determine sampler efficiencies, develop sampler selection guidelines, and provide for improved data acquisition and quality control. Need illustrated reference manuals.

10. Need to enhance FSCBG to handle non-parallel flight lines. (This task is under contract with Milt Teske.)

11. Test FSCBG & VALDRIFT models in complex terrain.

12. Need a "Rules of Thumb" manual that covers spray physics in complex terrain for both forestry and agricultural users. Dave Whiteman has submitted a proposal to do this task.

13. Pursue methods of enhancing exchange of information and technical data.

14. Need to enhance speed of FSCBG.

15. Need manual for selecting, use, capabilities, and limitation of meteorological equipment for operational and evaluation projects.

16. Need to write field procedures for use of the LICOR foliage density measurement system for use in forests and orchards. There may be a similar need for its use in agriculture.

17. Evaluate substitution of a volume source algorithm for certain line source algorithm in FSCBG.

18. Provide that canopy characterization allow for discrete changes in canopy type at least along the downwind axis and possibly in the crosswind axis. Many spray scenarios include discrete differences in receptors over the area of interest. Example would be a herbicide application to a site for conifer release or site prep with a tree buffer surrounding the site and a water body adjacent to the buffer zone. Often times the deposit to the water is of interest in assessing environmental impact. What effect does the tree buffer have on filtering out the drift cloud?

19. Continue to evaluate AGDISP, FSCBG, and other models with existing trial data.

20. Develop a grid-based topographical model that predicts propagation of shadows and related development of convective boundary layers.

21. Prepare a glossary of terms used in spray modeling, pesticide application technology, and environmental fate modeling.

22. Pursue development of expert systems as extension of spray application, environmental, and spray accountancy models.

III. RECOMMENDATIONS

The following high priority recommendations were developed from needs identified by those who participated in the Spokane meeting. They are listed in order of priority.

1. Work with the Spray Drift Task Force and New Zealand to conduct field characterization and drift tests of orchard airblast sprayers, and implement a validated model into FSCBG directed toward supporting safe and economical use of insecticides and forest resource protection.

2. Link GPS on-board aircraft system interactively to FSCBG for real-time decision making, tracking, accounting, and documentation. Provide for direct data input to FSCBG from aircraft spray monitors with FSCBG being capable of modeling each spray line separately.

3. Pursue development of expert systems as extension to FSCBG model for spray application, environmental, and spray accountancy.

4. Evaluate and demonstrate the potential of tree or shelter belts for reducing spray drift and implement findings into the FSCBG spray model.

5. Prepare a "hint book" and supporting documentation to provide guidance in collecting field data and to enhance the usability of FSCBG. This effort would encompass guidelines for sampling, meteorological instrumentation, data collection, quality control techniques.

6. Test both FSCBG and VALDRIFT with existing complex terrain field data to determine the influence of complex terrain on model predictions, and provide guidelines for future field studies and spray operations in complex terrain.

7. Pursue model development, enhancement, and technology transfer of FSCBG, with particular emphasis on simplicity and speed of operation, and extension of features suggested by user group members. Continue information exchange at technical meetings and in peer-reviewed journals, and user group activities, including training sessions, workshop, newsletters, and model updates and improvements.

IV. SUMMARY

The Fourth Meeting of the National Spray Model Steering Committee was held at Spokane, WA, on June 23-24, 1993. The committee reported on field testing and projects over the past year and discussed technology development needs concerning application technology and modeling drift, spray behavior, and environmental accountancy. The committee identified 22 technical needs and identified 7 that should be given high priority for funding. Again this year the committee noted the support of

management in encouraging and funding projects through technology development and other sources; and the progress that has been made in advancing the models over the past year. The participation and other support of our colleagues in industries, academia, and other agencies are recognized and appreciated, for without their involvement the utility of this committee would be weakened. My personal thanks to each of you in helping to develop, enhance, and transfer this technology. Our next meeting will be held at Kansas City, June 19-22, 1994 during the 1994 International Summer Meeting of the American Society of Agricultural Engineers. Please mark your calendar as we are looking forward to your continued participation.

[illegible]

[illegible]

[illegible] ... [illegible] to provide [illegible]

[illegible]

[illegible] development and technology [illegible]

APPENDIX A
Meeting Agenda

US Army

USDA ARS

US EPA

USDA APHIS

USDA Forest Service

MTDC

Research (NE)

Forest Pest Management

NA
R-8
Davis
Forest Health Management Center

PLANNED RESEARCH AND DEVELOPMENT

DEVELOPMENT NEEDS & RECOMMENDATIONS

5-YEAR PLAN

1700 **CLOSING**

Follow-up Actions

Next Meeting

APPENDIX B
Member Reports

[illegible]

[illegible]

[illegible]

[illegible]

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[illegible]

[illegible]

[illegible]

Dave Whiteman
Battelle

Battelle
Pacific Northwest Laboratories
Battelle Boulevard
P.O. Box 999
Richland, Washington 99352
Telephone (509) 376-7859

June 28, 1993

Dr. John W. Barry
USDA Forest Service/FPM
2121C Second St., Suite 102
Davis, CA 95616

Dear Jack:

I enjoyed attending the National Steering Committee Meeting on Spray Modeling last week in Spokane.

With this letter I am sending the outline of the document that the Meteorological Subcommittee is putting together entitled "Meteorological Measurements for Spray Drift Modeling." This outline arose from our subcommittee's work in the last year and was the key part of our committee report. You may wish to have this included in the minutes of the meeting.

In addition, I would like to summarize my recommendations to the committee. They were as follows:

- New developments with the Global Positioning System (GPS) and with lidar should be followed by the committee to see that these new technologies are used in the future to support spray modeling and spray operations. The GPS could greatly improve our ability to determine the actual locations of spraying and thus improve the "source term" in our model calculations. The lidar could be used to help us understand near-aircraft spray dispersion and could be used to improve the AGDISP model.

- A Rule of Thumb manual on complex terrain meteorology and its effects on spray dispersion should be produced.

- We should continue to monitor developments in full-physics atmospheric numerical modeling, as such models may become suitable for operational or applications use in the near future.

- We should continue to monitor research regarding the coupling and decoupling of valley and above-valley flows, as this is a key unresolved factor in our spraying operations in complex terrain areas.

- We should continue our efforts to evaluate present models using actual spray trials.

- A grid-based topography model should be developed to predict the propagation of shadows across regions of complex terrain after sunrise and the related development of convective boundary layers. Such a model could be used to help plan spray operations so that spraying could continue after convective boundary layers become too deep and winds too strong over the slopes that face most directly into the sun. The Forest Service has equipment and techniques that could be applied to develop such a model.

Thank you for the opportunity to participate in the meeting.

Sincerely,

Dave White

C. David Whiteman
Staff Scientist
Atmospheric Physics Group
ATMOSPHERIC SCIENCES DEPARTMENT

CDW:rak

Enclosure

OUTLINE

METEOROLOGICAL MEASUREMENTS FOR SPRAY DRIFT MODELING

Meteorological Subcommitteee
National Steering Committee – Spray Modeling

Alvin Womac
The University of Tennessee

THE UNIVERSITY OF TENNESSEE
INSTITUTE OF AGRICULTURE

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FAX: (615) 974-4514

June 29, 1993

John W. Barry
USDA Forest Service
Forest Pest Management
2121C Second Street
Davis, California 95616

Dear Jack:

Per our conversation at the meeting of the National Steering Committee - Spray modeling in Spokane, I am enclosing a brief statement of use and needs regarding FSCBG.

I am continuing to model drift in agricultural applications involving low canopy heights and spray release heights from a fixed monoplane (Turbo Thrush). Factors being evaluated and compared to field data include aircraft speed, height of spray release, length of boom, total spray rate, and droplet size. Boom "winglet" trials were not compared, due to significant alteration to the slipstream by the winglet.

New research includes the mechanisms of chemical evaporation, movement, and impact on air quality. This includes droplet size reduction and airstream sampling for chemicals in various phases. With respect to FSCBG, I believe that a detailed module on "chemical behavior" is greatly needed. I realize that this is a complex, yet necessary, area. Much data is lacking on this topic.

I appreciate the committee meeting and the tremendous impact that your group is having on spray application.

Sincerely,

Alvin R. Womac

Alvin R. Womac
Assistant Professor

Dave Valcore
Dave Esterly
Spray Drift Task Force

SPRAY DRIFT TASK FORCE

US EPA

COOPERATIVE RESEARCH DEVELOPMENT AGREEMENT

CRADA

FOR SPRAY DRIFT MODEL DEVELOPMENT

Working Group:

D. Esterly
J. Lin
T. Estes
S. Bird
T. Peterson

THE PROBLEM

The chemical-specified spray drift data currently required for registration are both **expensive** for the industry to collect and **inadequate** as a basis for OPP to use to perform a comprehensive exposure assessment.

Scope

The model(s) will be structured in a **two-level** framework to allow for both rapid assessment in a **regulatory** framework and for use in evaluating **drift management** techniques in a site specific context.

First

This effort will be closely coordinated with OPP to assure the assessment tool meets their regulatory needs.

Uses

Models will be evaluated by the ability to **predict** deposition of material. **Airborne concenrations** will be used for model evaluation as well following provision of code since all of the spray drift model do not provide these results as output.

The Key Understanding

Development of a structured two-level interface will be a major component of this function. ***Level 1 is used to establish limits and label restrictions.*** This level will have limited inputs. Level 2 will allow more flexibility of inputs and will be used to study drift management techniques and perform site specific evaluations.

Understanding Each Other

The Task Team will also develop a **glossary of spray drift terms and techniques.** The used of terms in the spray drift area is frequently inconsistent and confusing. This glossary will serve as a common basis when performing assessment and interpreting label descriptions.

Oversight

ORD researchers will review SDTF field trial results both in terms of data quality and the suitability of the data for model evaluation.

Evaluations

Task Team will develop a set of **rules** and **conditions** by which the models can be evaluated within the confines of normal application procedures and criteria to be used for model selection.

ORD NEEDS

The ***SDTF will supply EPA-ORD*** Task Team members all field trial data as available even if in a ***preliminary form.*** EPA-ORD Task Team members will use preliminary data only for Task Team activities. Preliminary data will be ***kept segregated*** and replaced by finalized data set when they are available.

Peer Review

A technical article will be prepared on model comparisons jointly by Task Team members with **ERL-Athens taking lead responsibility.**

Commitments

The **SDTF will fund programmer/ag engineer** to be stationed at Athens. ERL-Athens will supply facility, equipment and overhead support for this individual.

Commitments

SDTF will **supply funds for Task Team member** to visit fields, participate in Task Team meetings, and to meet with OPP and other SDTF representatives. EPA will assist in field data collection.

Dave Miller
The University of Connecticut

A Five Year (1993-1998) Plan

DEVELOPMENT OF OPERATIONAL MICROMETEOROLOGY TECHNOLOGY FOR AERIAL SPRAY APPLICATIONS

Cooperators:

University of Connecticut, Department of Natural Resources Management and Engineering:

David R. Miller, Professor of Forest Meteorology
Xiusheng Yang, Assistant Professor of Atmospheric Engineering

Pennsylvania State University, Pesticides Research Laboratory:

William Yendol, Professor of Entomology
Karl Mierzejewski, Associate Director
Center for Aerial Applications of Pesticides

USDA Forest Service, Northeast Forest Experiment Station:

Michael McManus, Project Leader
Center for Biological Control of Forest Insects and Diseases
Northeast Forest Experiment Station, USDA Forest Service

USDA Forest Service, Forest Pest Management

Richard Reardon
Northeast Region, State and Private Forestry
John Barry
Washington Office, Forest Pest Management
Jeff Witcosky
Northeast Region, Forest Pest Management

USDA Forest Service, Engineering
Harold Thistle
Missoula Technical Development Center

Continuum Dynamics, Inc.
Milton Teske, Senior Associate

USDA APHIS
Win McLane, Section Leader
OTISANGB, Ma.

NEEDS AND AIMS

Currently, no realistic guidelines are available on estimation of deposition and drift patterns of aerial spray operations subjected to wide variety of local atmospheric conditions just above the target forest canopy. The FSCBG model (Bjorklund et al., 1989) is a step in the right direction to utilize local weather inputs to calculate average spray movement, and hopefully can be used to define and predict some of these patterns. However, the application of FSCBG to particular spray operations is limited by the unavailability, and/or the inaccuracy associated with the estimation by non-standardized in situ measurements, of the necessary micrometeorology parameters (Miller et al., 1992). The model currently cannot account for the constantly changing atmospheric conditions during a spray operation either. In addition, adequate canopy descriptions are not available for use with FSCBG without a significant expenditure of time and labor at each spray site. Therefore, we propose, in the following five years (1993-1998), to develop 1) a canopy geometry data base for use with FSCBG, 2) guidelines to use standardized meteorological technology to estimate deposition and drift patterns with FSCBG, and 3) a procedure to adjust in process to rapidly changing atmospheric conditions.

The specific objectives are:

1. To establish a canopy geometry data base which includes typical profiles of canopy density of each of the major timber types, from which users can quickly estimate the necessary canopy architectural parameters by simple, standard forest measurements;

2. To develop site specific guidelines to estimate deposition and drift patterns using FSCBG, including

   1). Identification of the most important factors of forest structure (edge and clearings, for instance) and topography affecting transport processes for a given site;

   2). Procedural outlines to define and take the standard local meteorological measurements; and

   3). Guidelines to estimate flow conditions over the spraying area from the standard measurements;

3. To develop in process adjusting techniques to rapidly changing atmospheric conditions during aerial spray operations, specifically

   1). To compare the available monitoring

techniques (on plane sensors, mini-sodar, etc.) in aerial application and select the most suitable one for monitoring and predicting changing atmospheric conditions;

2). To develop guidelines to translate the measurements into in process adjustments to insure accurate application of the spray material.

PROCEDURES

A. PROCEDURES TO MEET OBJECTIVE 1.
LEAF AREA PROFILE MEASUREMENTS

Progress in the transfer of much of the new research results to operational tools and the extensive adaption and use of tools, such as FSCBG, depends on the availability of vertical profiles of foliage area density, or similar measurements. The size and variability of forest canopies, however, make widespread hand sampling of foliage distributions out of the question. There has been an extensive amount of research on the use of light penetration of canopies to remotely estimate their leaf areas (Anderson, 1971; Bonhomme and Chartier, 1972; Wang and Miller, 1987; and others). The most sophisticated of these studies utilized hemispherical or "fisheye" photographs for the field measurements. In 1989, an electronic light sensor was marketed (Welles and Norman, 1991) which greatly eased the measurement and data reduction tasks. We have tested this sensor and combined it with our auto-leveling system (Wang et al., 1992), which allows us to measure the leaf area profiles in any forest stand more accurately than before.

A data base of typical leaf area profiles of each of the extensive forest types in the United States is badly needed for aerial applications. Since the branching and leafing habits of each tree species are consistent from site to site (Horn, 1970; Wang and Miller, 1987), these typical profiles can be used whenever operations are conducted in stands with species mixes similar to those measured. The accumulated library of typical leaf area profiles can be made available as look-up tables in models or on electronic media, to other users of spray materials. The measurement project will:

1. Select stands with known composition and stocking for measurement from long term management, research and inventory plots throughout the United States. Preferably, stands with different stocking levels in each forest type will be found. Approximately 50 different major forest types exist. Most of these should be sampled.

2. In each sample stand make at least five profile measurements using a movable telescoping tower, self-leveling platform and LAI-2000 sensors as described in Wang et al. (1992). Also, a cruise will be conducted in each stand which does not have a recent inventory available.

3. Establish the data base (library) of leaf area density profiles as a function of species composition and stocking.

B. PROCEDURES TO MEET OBJECTIVE 2.
DEVELOPMENT OF SITE SPECIFIC GUIDELINES AND INPUTS FOR FSCBG

Constantly changing micrometeorological conditions (stability, temperature, wind direction and speed, humidity, turbulence scale) above and within a forest canopy result in constantly changing spray movement patterns (Anderson et al. 1992). Characterization and categorization of the various conditions that can be expected during spray periods are needed for the pre-operational planning of a spray operation. The use of prediction models, such as FSCBG, for each expected combination of conditions will allow the estimation of the variety of spray deposition patterns prior to spraying.

To establish these guidelines we will

1. Analyze available micrometeorology data, especially that from the Black Moshannon Pennsylvania experiments (Miller el al. 1992, 1993), to define the dynamics of the hardwood canopy roughness layer during spray days.

2. Develop a procedure to infer the atmospheric conditions in the canopy roughness layer from local weather observations.

3. Define the known topographic effects on micrometeorological processes.

4. Define known interrupted canopy effects using the models of Miller et al. (1991).

5. Modify FSCBG to incorporate topographic effects.

6. Modify FSCBG to incorporate interrupted canopies.

C. PROCEDURES TO MEET OBJECTIVE 3.
FIELD EXPERIMENTS OF DRIFT AND SPRAY MOVEMENT

Field experiments in the western forests (WIND, Seed Orchard, Gambel Oak) and eastern hardwoods (Black mo 1988, 1990, 1992) have provided some background and data to develop the guidelines above. But only in the western forests have experiments provided data in rough terrain and only in project WIND

(Miller et al. 1989; Wang, 1989; Wang et al 1991 etc) have limited experiments looked at edge effects. No measurements to date have detailed the movement of spray aerosols in the air, and rigorously followed drift patterns. The advent of a new laser radar (lidar) technology should allow field measurements of many of these phenomena. The measurements can be used to test and modify the computer routines being developed to guide spray operations. Specifically field trials are necessary to:

1. Test algorithms to use on-plane instrumentation and ground measurements with mini-sodar to monitor the changes in atmospheric conditions.

2. Detail the effects of aircraft orientation to the wind on the spray cloud movement, and study the feasibility of <u>in process</u> adjustment.

3. Verify the canopy roughness, edge and clearing effects on the spray dispersion and movement in the drift models, and the topographic interactions in drift models.

Along with the field trials above, wind tunnel experiments also are needed to recalculate the turbulence effects on the evaporation of BT and other spray materials.

D. EQUIPMENT DEVELOPMENT

The development work listed to meet the objectives above will involve the acquisition and testing of several instrumentation systems. These are:

1. A mini-lidar (laser radar) to measure and map the movement of spray in the air.

2. A mini-sodar (acoustic radar) for instantaneous measurement of the wind speed, wind direction and turbulence measurements above the canopy.

3. Spray airplane monitoring systems for time recording of the airplane position, speed, and spray rate.

4. Telescoping, self-leveling poles and platforms for LAI measurements.

SCHEDULE

```
Task                              Year
                                  1      2      3       4      5
-----------------------------------------------------------------

Equipment Development:

Lidar feasibility analysis        ---------
Lidar acquisition                        ---------
Mini-sodar acquisition            ------------------
LAI profile hardware acquisition  --------

Leaf Area Geometry Inventory:

Tree stand/sample site selection  -----------------
Crew Training                     ------
Field Measurements                   ----------------
Data Reduction                           ----------------
Incorporation of Data Tables into FSCBG                 ----------

Site Specific inputs:

Analyze existing micromet data    --------
Define topography effects         ------------------
Define broken canopy effects      ---------------------
Algorithm to infer canopy micromet conditions   ---------------
Modify FSCBG                                            ------------

Field Trials:

Air craft orientation  effects      ----------------
Verification of Topography effects       -------------------
Verification of interrupted canopy model        ---------------------
Wind tunnel evaporation study                ------------
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Progress Report

on - 5 Year Plan to

DEVELOP OPERATIONAL MICROMETEOROLOGY TECHNOLOGY FOR AERIAL SPRAY APPLICATIONS

David R. Miller

6/23/93

At the 1992 summer meeting of the National Spray Modeling Committee the needs to develop a canopy structure data base, to develop a method to measure spray movement in the air, and to have better operational meteorology measurement equipment were discussed. This discussion led to the appointment of the "canopy" subcommittee and the "meteorological" subcommittee. At the suggestion of chairman Barry, the discussions and recommendations presented were used to develop the attached 5 year plan.

Several of the items recommended by the plan have been initiated in the last 12 months.

Equipment Development:

A field study to determine the feasibility of lidar technology to measure spray movement in the air was conducted in June 1993 at State College Pa. The data are currently being analyzed but the preliminary results have indicated that the lidar technology will do everything we expected and more. The data analysis will be completed this summer and used to write a proposal cooperatively between NEFAAT and the USFS to obtain (build or buy) a mini-lidar for use in the field trials portions of the this 5-year plan.

A standard SODAR, provided by H. Thistle, was used simultaneous with some measurements from the UCONN micormeteorological tower in a preliminary trial in June 1993 and the data are now being reduced.

Leaf area geometry inventory:

A cooperative project between the NE FPM and UCONN, directed by Jeff Witcosky, has developed procedures and equipment to measure LAI profiles in tall forest stands. A number of "typical" hardwood forest stands of different types have been selected from Michigan to Georgia and a three year measurement schedule was started in May 1993.

We have tested the sensitivity of FSCBG to the LAI inputs.

Site Specific Inputs:

We have been analyzing the existing micromet data - results specify the wind and turbulence regimes which result the optimal spray dispersion.

Research trials:

During the lidar experiment we took preliminary data at different aircraft orientations in order to design a specific experiment.

We have completed measurements of the evaporation rates of a number of types of BT and have developed a modification of the FSCBG model evaporation routine for them.

PRODUCTS:

Miller, D. R., Y. Wang, K. Ducharme, X. Yang, K. Mierzejewski, M. McManus, R. Reardon. 1993. Micrometeorological Effects On Spray Pentration In Hardwood Forest Canopies. J Agr and Forest Meteorol. (Submitted) also to be presented at the International Conference on Wind In Forests, Edinburgh, July 1993.

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Miller, D. R., X. Yang and J. Witcosky. 1993. Guidelines for measurement of Leaf Area Profiles in Tall Forests. (In preparations).

PLANS AND RECOMMENDATIONS FOR THE 1993-1994 YEAR:

* Propose and acquire a Lidar specifically designed for Aerial Spray studies.

* complete the meteorology subcommittee report on recommended meteorology measurements.

* thoroughly test a mini-sodar against micromet tower data to see if it can be used operationally to provide the necessary profile data before and during spray operations from the ground.

* Continue the Leaf area Geometry Inventory project

Progress Report

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* Continue the Leaf area Geometry Inventory project

VERTICAL DISTRIBUTIONS OF CANOPY FOLIAGE AND BIOLOGICALLY ACTIVE RADIATION IN A DEFOLIATED/REFOLIATED HARDWOOD FOREST*

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(Received __________; revision accepted __________)

ABSTRACT

Yang, X., Miller, D. R. and Montgomery, M. E., 1993. Vertical distributions of canopy foliage and biologically active radiation in a defoliated/refoliated hardwood canopy. Agric. For. Meteorol., 00: 000-000.

Vertical profiles of foliage area and solar irradiance in the ultraviolet-B (UVB, 280-320 nm), photosynthetically active (PAR, 400-700 nm), and total spectral regions were measured simultaneously in a partially refoliated mixed oak forest, previously defoliated by Gypsy Moth, using canopy analyzers and broadband radiation sensors mounted on an auto-levelling platform of a mobile, up-down lifting tower. Measurements were taken at 10 locations in the stand; and nine vertical positions at each location. Temporal variations also were evaluated in a second experiment with the same protocol at a fixed location. Downward cumulative leaf area index was fit to the Weibull cumulative distribution function. Good agreements were found between the data and their Weibull representations, with non-linear R^2

*Use of trade names implies neither endorsement of products by University of Connecticut or USDA nor criticism of similar ones not mentioned.

value averaged 0.98 for the 10 fittings of the spatial samples, and >0.99 for the means. Both the scale and shape parameters of the Weibull cumulative distribution function were significantly correlated and decreased with the canopy leaf area index. As an indicator of the internal consistency of the canopy analyzers, the temporal variation of the leaf area measurements at the fixed location was about 10% for solar zenith angle in the range of 30 to 45 °. The irradiance of UVB, PAR, and total solar radiation within the canopy were all found to attenuate with downward cumulative leaf area index, and their vertical distribution could be reasonably well described by Beer's law of attenuation. The attenuation rate was the greatest for UVB , smallest for total, and intermediate for PAR. Extinction coefficients were 0.86, 0.79, and 0.64 for UVB, PAR, and total solar energy, respectively. Ratios of UVB to PAR, UVB to total, and PAR to total also were shown to decrease with cumulative leaf area index. The long term change in the flux ratio of UVB to PAR to monitor the forest adaptation to, and damage level from, increased exposure to UVB was recommended.

INTRODUCTION

The depletion of stratospheric ozone and the reported corresponding increase in ground-level ultraviolet-B radiation (UVB, 280-320 nm in wavelength) (Blumthaler and Ambach, 1990; Correll et al., 1992) has triggered concerns about the consequences on our natural ecosystems (Caldwell et al., 1989; Krupa and Kickert, 1989; Teramura et al., 1990; among many others). Although UVB accounts for only a small fraction of the total solar energy reaching the ground (less than 7% for the whole ultraviolet band), it is of great significance to ecosystems due to its effect on macromolecules such as proteins and nucleic acids (Caldwell, 1981). Differential species reactions to UVB may have a significant effect on competition among plants (Gold and Caldwell, 1983). Any responses by trees would potentially change the food chains and environmental patterns of insects and other forest organisms. Also, increased UVB flux may be lethal to some bacteria and viruses and cause degradation of pesticides or biological agents. While comprehensive research has been

conducted on the transfer and distribution of PAR and/or total** radiation in plant stands, the UVB regimes in vegetation are not yet known, largely due to the absence of reliable sensors.

The mean radiation environment within a horizontally homogeneous forest canopy has been widely described by Beer's law, which states that the downward transmission of radiation follows an exponential profile scaled by the cumulative leaf area index (Landsberg, 1986; Kozlowski et al., 1991; Russell et al., 1989). Various techniques for modeling radiation regimes in plant canopies have been reviewed extensively by Ross (1981) who noted that the interactive processes of absorption and scattering make plant architectural parameters an integrated part of radiation studies. A complete study on radiation transfer in forests must include both distributions of radiation irradiance and forest architectural parameters. Although essential, data on forest architecture has not been readily available because of the lack of easy and accurate methods for direct measurements before the recent development in spatially integrating canopy analyzing systems (Gower and Norman, 1991; Lang et al., 1991; Wang et al., 1992; Welles, 1990).

The general objective of this study was to experimentally characterize the mean vertical distributions of light-intercepting elements and irradiance of UVB, PAR, and total radiation in a hardwood forest defoliated by gypsy moth (*Lymantria dispar* L.) and then partially refoliated. One application of the results will be to describe the biological radiation environment for large scale aerial application of photo-degradable pesticides on northern temperate forests.

MATERIALS AND METHODS

Site

The measurements were made on August 25 and 26, 1992 in the Black Moshannon State Forest near State College, Pennsylvania. The forest was a mixed oak type that was defoliated by gypsy moth during the early season in June and refoliated in July and August. The site was on a mesa where the topography was relatively flat and uniform. On the

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**In this article, we follow the convention of using *total* to denote the broadband or whole spectrum radiation, while using *global* to represent the sum of direct and diffuse components.

northwest side of the forest stand there was a large clearing (>500×500 m) where the reference measurements were made. The latitude, longitude, and altitude of the site are 40.08 N, 77.08 W, 631 m, respectively. The local sky conditions ranged from clear to partially cloudy during the experimental periods on both days.

Instruments

The profiles of leaf area and radiation irradiance in the canopy were measured using a mobile, up-down lifting tower with an auto-levelling instrument-mounting platform described by Wang et al. (1992). In brief, the tower consisted a hydraulic personnel lift and a pneumatic telescoping pole, with a up-down moving range of 2.7-17.6 m. A platform was mounted on top of the telescoping pole by a spherical joint. Sensors were mounted on the platform with their top surfaces leveled at a same elevation. The platform was pre-leveled and kept level automatically during the measurements.

A LAI-2000 canopy analyzer (LI-COR, Inc., Lincoln, NE) was mounted on the platform to measure the vertical profiles of canopy elements. The LAI-2000 sensors are made up of 5 concentrically arrayed ring-shaped fisheye light sensors to detect and integrate gap fractions of a canopy in the range of 0-74° zenith angle (LI-COR, 1992; Welles, 1990). By nature of design, the sensors work best when the sun is obscured and underestimate foliage area under direct illumination. Use of snap-on view restrictors and making measurements when the sun is low or obscured by clouds have been recommended (Welles and Norman, 1991). Also, the LAI-2000 sensors do not distinguish leaves from stems. The measurements with LAI-2000 canopy analyzers, therefore, includes bark area of the canopy. Although the common terms of leaf area and leaf area index were adopted in this study, the inclusion of bark area in the measurements hereby is specially emphasized because the refoliated forest had less leaf area than fully foliated forest canopies.

Mounted with the canopy analyzer on the platform were a set of sensors to measure the broadband irradiance of UVB (YMT-UVB_{BE}, Interscience Technology, Silver Spring, MD), PAR (LI-190SA, LI-COR, Lincoln, NE), and total radiation (LI-200SA, LI-COR, Lincoln, NE). The YMT-UVB_{BE} sensors used in this study were developed using a combination of filters with an appropriate photocell, measuring radiation in the spectral range of 255-325 nm in wavelength weighted by the "biological effectiveness" (Interscience

Technology, 1992). Since scientific literature was not yet available concerning UVB measurements using the YMT radiometers, two UVB sensors were mounted side by side on the platform to check their calibration stability and compatibility. The LI-200SA sensor for measuring total radiation was chosen for its availability and convenience rather than accuracy, because the sensor does not have a uniform sensitivity to all wavelengths. In plant canopies where the spectral distribution of radiation is modified by selective absorption, the LI-200SA may compare unfavorably with first class thermopile pyranometers.

Another complete set of sensors and data acquisition system, for reference readings without the canopy, were mounted on a separate platform located 2.5 m above ground in the center of the adjacent clearing. These reference sensors were run continuously at a 5-s sampling rate. All sensors were calibrated by their manufacturers before the study. The two canopy analyzers also were intercalibrated before and after use following the operational instructions (LI-COR, 1992). While data taken by the LAI-2000 canopy analyzers were recorded by dedicated dataloggers accompanying with the sensors, radiation measurements were acquired by generic dataloggers (21X, Campbell Scientific, Logan, UT). All data acquisition devices were synchronized right before taking the measurements.

Procedure

Measurements of the profiles of foliage area and radiation irradiance on August 25 were made at 10 locations in the stand, 20 m apart from each other, to obtain a spatial average. The locations were at least 200 m from any forest edge. At each location where leaf area index and radiation measurements were taken, the species composition, height of the forest, and stand basal area were determined with the variable size plot technique according to Husch et al. (1972). Leaf area and radiation data were collected twice at each location, one during the ascent and another during the descent of the tower, at nine vertical positions, i.e., 2.75, 4, 6, 8, 10, 12, 14, 16, and 17.5 m from the ground. For each combination of location and height, six readings were logged in a 30-s period from which means were computed for each measured parameter.

The sky was partially cloudy on August 25. Because the LAI-2000 canopy analyzers underestimate foliage area under direct illumination, snap-on view restrictors were used on the canopy analyzers to block the quadrant of sky where the sun was located, and efforts

were made to ensure that the same quadrant of sky was blocked for both sensors on the platform and in the clearing (LI-COR, 1992). Measurements at five out of 10 locations also were taken during the periods that the solar elevation was lower than 35° when the solar radiation contained a significant diffuse component.

The temporal variation of the foliage area and radiation measurements were examined in another experiment in the morning of August 26 at a fixed location. The procedure of data collection was the same as for spatial sampling, and was repeated 10 times at 15-min intervals. The weather condition was about the same as on August 25 and the same restriction technique was applied to the canopy analyzers.

Data analysis

The leaf area measurements*** were calculated with the readings at the clearing as A (above canopy) and the readings in the forest as B (below canopy). Data were combined and processed from the two readings using the LAI-1000 software provided by LI-COR, and were averaged for each height at each location. Since the calculated value at each height represents the leaf area index above the sampling point, the nine data points at different heights readily produced the corresponding cumulative distribution. The Weibull cumulative distribution function (Campbell and Madden, 1990), defined as

$$\ell(d) = 1 - e^{-\left(\frac{d-a}{b}\right)^{c}} \qquad (1)$$

was used to fit and describe the vertical profile of the cumulative leaf area index, where d is the depth from the top of the canopy ($=h_c-z$, where h_c is the maximum canopy height and z is the vertical distance from ground), $\ell(d)$ is the normalized cumulative leaf area index (ranged from 0 to 1) at a given depth d, and a, b, and c are model parameters. The location parameter a represents the smallest d for canopy elements to appear and was preset to zero, the scale parameter b is the value of d that covers 63% of the foliage (ℓ=0.63), and the

***Leaf area or leaf area index will be used hereafter to report the measurements with the LAI-2000 sensors, although the measurements contained a large portion of bark area contributed by non-transpiring elements such as limbs and stems, as discussed in the previous section.

shape factor c provides a measure of distribution skewness. Values of c less than 3.6 represent positive skewness and vise versa. The Weibull distribution was fit using nonlinear least squares with the statistical software BMDPAR (BMDP, 1988) for each location averaged over the data taken during the ascent and descent of the tower. Regression analyses were conducted for the Weibull parameters in relation to stand leaf area index.

For assessing the relative magnitude and distribution of each radiation component in the forest, the measured variables used for data analysis were the radiation transmission functions (the ratio of irradiance measured at a given height to that above canopy) rather than the absolute values of irradiance. Measurements in the clearing were used exclusively as the above-canopy values. The Beer's law, expressed as

$$t = e^{-kL} \qquad (2)$$

was used to describe the radiation profiles in the forest, where t is the canopy transmission function for a given band of wavelength (UVB, PAR, or total) at a given depth designated by the cumulative leaf area index, L, and k is the corresponding extinction coefficient. Linear regression analyses on the logarithmic transforms of t in relation to L were conducted to determine the k values for UVB, PAR, and total solar radiation. Ratios of UVB to PAR, UVB to total, and PAR to total were calculated for each combination of location and height. The dependence of these three ratios on leaf area index also was assessed by correlation and regression analyses. Since the direct readings of the PAR sensors were in units of $\mu mol/s.m^2$, the readings were converted to W/m^2 just for calculation of the ratios, based on the spectral response given by LI-COR (1991). The extinction coefficients and mean Weibull parameters were used to calculate the mean radiation profiles using eqn. 2 for each spectral regions.

RESULTS

Canopy foliage

The forest was predominantly oak (84%), including white oak (*Quercus alba*, L.), black oak (*Quercus velutina*, Lamarck), red oak (*Quercus rubra*, L.), chestnut oak (*Quercus prinus*, L.), and some red maple (*Acer rubrum*, L.) and sassafras (*Sassafras albidum*, L.).

The size distribution of each species is summarized in Fig. 1. Ten basal area measurements on the experimental site averaged 20.4 m^2/ha with a standard deviation of 5.1 m^2/ha. The maximum height of the forest was about 20 m.

The mean leaf area index of the forest was 1.69 measured by LAI-2000 sensors; thus the foliage was about 50% less than the full summer foliage measured in similar, nearby stands (Wang et al., 1992). Measurement means and standard deviations of the cumulative leaf area index at different depths taken on August 25 are shown in Fig. 2 by the symbols (connected by a dashed line) and error bars, respectively. The solid smooth line shows the corresponding fit of the mean data to the Weibull cumulative distribution function (eqn. 1), for which the nonlinear coefficient of determination (R^2) was 0.995. For the 10 fittings of the individual replicates on August 25, the nonlinear R^2 averaged 0.98 with a standard deviation of 0.02, indicating good agreements between the data and their Weibull representations.

Inserted in Fig. 2 are the relationships between the Weibull parameters and leaf area index. Ten pairs of fitting parameters for the data of August 25 were used for the regression analyses. Both b and c declined with increasing LAI, but the regression of c on LAI was only marginally significant (P=0.05). The R^2 value for the relationship between b and LAI was 0.88, with both predictors significant at $P \leq 0.001$. Regression analysis also was conducted for the Weibull parameters in relation to the basal area of each location but failed to reveal any significant dependence of either b or c on the stand basal area.

Some of the variability may be attributed to variations in the measured leaf area with solar zenith angle. The vertical profiles of leaf area measured on August 26 are similarly shown in Fig. 3. The solid circles in Fig. 3 are means of the measurements over the 10 replicates taken at the same location in 15-min intervals, with the solar zenith angle ranged from 30 to 45°. Leaf area index measured on the location varied from 1.18 to 1.58 with a coefficient of variation of 0.10. The standard deviations are plotted as the error bars in Fig. 3, which represent the variability of the means at each level as elevation and obscuration of the sun varied during the period of measurements, and therefore would indicate the internal consistency of the LAI-2000 canopy analyzers. The maximum values were recorded when the solar zenith angle was about 30° while the minimums were found when the solar zenith was in between 35 to 40° (see the insert in Fig. 3). This does not mean, however, that the

sensors tend to underestimate foliage area at low solar positions. In fact, among the measurements taken on August 25, maximum values of leaf area index were all found at either high or low solar positions (X. Yang, unpublished). It seemed that the canopy analyzers tended to have a minimum response at some middle elevation of the sun. The effect, however, could not be singled out with the measurements in this study.

Biologically active radiation

The maximum above canopy readings recorded for the two-day experimental period were 1601 mW/m^2, 2046 $\mu mol/s.m^2$ and 1016 W/m^2, for UVB, PAR, and total irradiance respectively. The mean ratios above canopy of UVB to PAR, UVB to total, and PAR to total were 3.6×10^{-3} (standard deviation $\sigma=1.1\times10^{-3}$), 1.7×10^{-3} ($\sigma=0.5\times10^{-3}$), and 0.49 ($\sigma=0.16$), respectively. Due to the partially cloudy sky conditions, the measurements fluctuated over a large range, especially in the mornings. The maximum difference between the two UVB sensors was less than 5% during noon periods and within 10% for all the measurements.

The irradiance measurements of UVB, PAR, and total radiation attenuated with depth or cumulative leaf area index. Shown in Fig. 4 are the vertical profiles of UVB, PAR, and total transmission functions (irradiance measurements at the given locations scaled by the simultaneous above-canopy measurements), averaged over the 10 replicates on August 25. Generally, UVB attenuated the most and total radiation the least, indicating that the absorptivity of leaves must be the greatest for UVB and smallest for total. The patterns of PAR, intermediate between UVB and total, followed total in the top part of the canopy but was similar to UVB in the understory.

The difference in downward attenuation between UVB, PAR, and total was shown to increase with depth (Fig. 4). To assess if the downward attenuation through canopy of UVB, PAR, and total were different, ratios of UVB to total, PAR to total, and UVB to PAR were calculated. Correlation and regression analyses showed a decreasing tendency with increasing cumulative leaf area index for all the three ratios (Fig. 5). The highest correlation was found for the ratio of PAR to total (R=-0.58), and the decrease was more significant for UVB and PAR to total than for UVB to PAR.

Regression analyses for the logarithmic transforms of the canopy transmission

functions in relation to the cumulative leaf area index indicated that Beer's law approximated reasonably well the global radiation (direct plus diffuse) transfer. All regressions were significant at $P \leq 0.001$ and the results are shown in Fig. 6. The regression fit was the best for UVB and the worst for total, with R^2 values being 0.90, 0.89, and 0.84 for UVB, PAR, and total, respectively. The extinction coefficient k was the greatest for UVB (0.86), smallest for total (0.64), and intermediate for PAR (0.79). Using the mean Weibull representation of the cumulative leaf area index (Fig. 2) and the above extinction coefficients, vertical profiles of UVB, PAR, and total irradiance were calculated using Beer's law (eqn. 2) and plotted with the measurements in Fig. 7.

Data on temporal variations taken on August 26 suggested that all the ratios and extinction coefficients decreased with solar zenith angle (or increased with solar elevation) during the period of measurement. The correlation coefficients (R) were all negative and ranged from -0.21 to -0.80. The ratios and transmission functions also fluctuated with sky conditions, indicating the dependence of the ratios of diffuse to total radiation in the three spectral regions on sky cloud cover.

DISCUSSION

On data collection

Several indirect methods have been recently developed to measure canopy structure by estimating foliage gap frequencies (Lang et al., 1991) or fractions (Welles, 1990). Sensors measuring gap frequencies have to move horizontally within the canopy along a transect and are not easily applicable particularly to determination of vertical profiles. The LAI-2000 canopy analyzers are based on the theory of fisheye optics which measures diffuse radiation simultaneously in five distinct angular bands from a fixed point. By the nature of design, the LAI-2000 sensors work best if the sky light is diffuse. However, practical, simultaneous measurements of canopy structure and radiation profiles, such as in this study, require that canopy analyzers work under all sky conditions. Our study showed that leaf area readings tended to change even if the recommended view restrictions were strictly followed. We suspect that the reflection of direct light from leaves to the sensors is a function of the mean leaf inclination, as evidenced by our temporal measurements which showed a minimum

response zenith angle under direct illumination. Nevertheless, this gap fraction technique provided a very convenient way to estimate the vertical foliage profiles of tall and rough forest canopies, although it is still new to the scientific community and may need substantial improvement.

Radiation irradiance in all three spectral regions fluctuated rapidly during most of the daytime, especially for a sky with fast moving cumulus clouds. Without separate sensors for measuring the simultaneous quantities above the canopy, the temporal variation of radiation would introduce a great deal of error in calculated leaf area and radiation profiles. If routine measurements are to be made, an additional set of sensors dedicated for readings above canopy is necessary. Because of the non-uniform sensitivity of the LI-200SA to all wavelengths, accurate measurements would require comprehensive calibrations against, or use of, more reliable sensors to measure the total radiation. In addition, since measurements have to be taken through small canopy gaps, data may somewhat overestimate radiation and underestimate leaf area. Therefore, sites have to be chosen carefully to be fairly representative of the canopy or corresponding corrections have to be applied.

The mobile, up-down lifting system provided an efficient way of collecting foliage area and radiation profiles simultaneously in forests. A database for this sort of information for the major forest types acquired through systematic measurements would be a valuable asset for the forest meteorology community. However, care must be taken to develop a protocol to accomplish the task which minimizes the errors noted above.

On Weibull representation of cumulative leaf area index

The Weibull cumulative distribution function was found to fit the mean cumulative leaf area index well (Figs. 2 and 3). In addition, with the location parameter (a) preset to zero, there are only two parameters, i.e., the scale parameter b and the shape parameter c, which need to be determined. Since b represents a value of depth that contains 63% of the leaf area while c provides a measure of the distribution skewness, both b and c should be a function of the canopy height for a fully foliated canopy, assuming that the crown structure of a particular species is consistent (Horn, 1971; Wang et al., 1992). Compared to many other distribution functions used for the same purpose for different types of forests (Beadle et al., 1982; Halldin, 1985; Massman, 1981, for example), the Weibull cumulative distribution

function is more practical in both fitting and explaining the data of this study.

A useful index, the half depth, where the cumulative leaf area index is 50% of the canopy leaf area index, can be easily derived from the Weibull parameters by $d_{50}=0.693^{1/c}b$. From the values of b and c for the combined data shown in Fig. 2, the half depth was calculated as just less than 9.85 m for this defoliated/refoliated canopy, i.e., 50% of the foliage is confined within the top 9.85 m of the canopy. The foliage area of the canopy, therefore, was about evenly divided between the top and lower part of the canopy. This was also supported by the mean value of the shape parameter c. For a normal distribution, c would be 3.6. For $c<3.6$, the distribution is positively skewed, i.e., many leaves are at the top of the canopy. Although the c value for the combined data was around 2.6 (Fig. 2) which indicated a somewhat positively skewed distribution of the foliage area, the mean value of c over replicates was about 3.4 (insert in Fig. 2), showing that the foliage area was not much different from a normal distribution. Both the scale parameter b and shape parameter c, however, showed a tendency to decrease with leaf area index (see the insert in Fig. 2). A decrease in either b or c would indicate that as leaf area index increases into a fully foliated stand, more leaves will be found at the canopy top. A fit to the previous data set (Wang et al., 1992) for a nearby, similar, but fully foliated mixed oak canopy ($L=3.4$, $h_c\approx17$ m) yielded the values of b, c, and d_{50} of 7.8, 1.9, and 6.5, respectively, showing a much more positively skewed profile. This was generally in agreement with the findings of Hutchinson et al. (1986) and Wang et al. (1992) that the majority of the overstory foliage in fully foliated oak forests is located near the top of the canopy.

On the biological radiation environment

The YMT sensors seemed to yield reasonable readings compared to other reports of UVB measurements and estimates. For example, using a spectral radiometer, Lee and Downum (1991) reported that the UVB irradiance at Miami, Florida, was around 3.7 W/m^2 in summer, 1.8 W/m^2 in winter, and nil under a subtropical canopy. Grant (1991) reported that the average irradiance during noon for a horizontal plane surface at the base of a corn canopy was 0.08 W/m^2 in the NUV waveband (305-350 nm) at West Lafayette, Indiana. And the long-term average UVB fluxes on clear days at solar noon at Edgewater, Maryland was about 2.5 W/m^2 (Correll et al., 1992). In this study, the irradiance of UVB above the canopy

peaked at midday around 1.6 W/m^2.

As radiation transfers down through the canopy, we expect UVB and PAR to decrease more than total radiation because of the high absorptivity of leaves to the biologically active radiation. This has been conceptually supported by our measurements (Figs. 4-7). The attenuation rate of UVB was the highest while that of total radiation was the lowest in this study. Although data are not available on the radiative properties of hardwood tree leaves with respect to UVB, it is generally believed that in this waveband the absorptivity of green leaves is greater, while the reflectivity and transmissivity are smaller, compared to the other two spectral regions. For $L=1.69$, the canopy transmission function at ground surface averaged 0.23, 0.26, and 0.34 for UVB, PAR, and total radiation, respectively. If leaf area index was 3.4 as for the fully foliated canopy in Wang et al. (1992), the values would be reduced to 0.05, 0.07, and 0.11, for the three spectral regions, respectively, which is in general agreement with other studies in the literature (Grant, 1991; Lee and Downum, 1991).

The difference in attenuation rate results in a negative proportion between cumulative leaf area index (or canopy depth) and the ratios of UVB to PAR or total radiation, as indicated by Fig. 5. We believe long term measurements of changes in the flux ratio of UVB to PAR is a simple way to monitor the forest adaptation to, and damage level from, increased exposure to UVB. Studies have shown that an increase in UVB flux would generally cause photosynthetic depression and hormonic disorder in exposed leaves (Caldwell, 1981; Kozlowski et al., 1991). The top leaves, while intercepting and absorbing most of the PAR for photosynthesis in healthy canopies, would be most vulnerable to damages caused by UVB. If the photosynthesis in the top canopy leaves was depressed (less PAR would be absorbed there), we would expect a reduction in the ratio of UVB to PAR at lower leaves. The changes in this flux ratio, therefore, would indicate some basic changes in the functioning of forest ecosystems.

CONCLUSIONS

This study demonstrated a convenient way to simultaneously determine the vertical profiles of foliage area of, and solar irradiance in UVB, PAR and total spectral regions within, a tall and rough forest canopy. The technique could be used to evaluate both the

spatial and temporal variations of the leaf area index and solar irradiance, and quantify the essential parameters to describe the one-dimensional (vertical) biological radiation environment using the popular and simple Beer's law of attenuation.

The Weibull cumulative distribution function was found to provide a good fit to the cumulative leaf area index of the hardwood forest canopy. Fitting parameters of the Weibull cumulative distribution function and their relations with stand leaf area index also provide relevant description of the location, dispersion, and skewness of the foliage elements within the canopy.

Simultaneous measurements on solar irradiance at the three wavebands revealed some important similarities and difference in radiation distribution and transfer among UVB, PAR, and whole spectrum solar energy. Vertical radiation profiles of all three wavebands were shown to be reasonably described by Beer's law. The attenuation rate, however, was the highest for UVB, lowest for total, and intermediate for PAR. Ratios of UVB to PAR, UVB to total, and PAR to total also were shown to decrease with cumulative leaf area index. The results of this study indicated that the top leaves are most vulnerable to damages caused by UVB, and we recommend the use of the long term change in the flux ratio of UVB to PAR to monitor the forest adaptation to, and damage level from, increased exposure to UVB.

ACKNOWLEDGEMENT

This research was supported by the United States Department of Agriculture Forest Service (USDAFS) Global Change Research Program cooperative agreement 23-659, USDAFS Forest Pest Management cooperative agreement 23-236, and USDAFS Northeastern Forest Experiment Station cooperative agreement 42-583. The authors wish to thank Dr. Jeffrey J. Witcosky, USDA Forest Service, Forest Pest Management, for his assistance in collecting the data. This paper is Scientific Contribution No. 1464 of the Storrs Agricultural Experimental Station, University of Connecticut, Storrs, CT 06269.

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FIGURE LEGENDS

Fig. 1. Species and size class distribution of trees in the experimental hardwood forest.

Fig.2. Vertical profile of the cumulative leaf area index of the forest. Symbols and error bars are means and standard deviations of the measurements taken at 11 different locations. The solid smooth line shows the corresponding fit of the mean data to the Weibull cumulative distribution function (eqn. 1). Insert: relationship between the Weibull parameters and leaf area index.

Fig.3. Temporal variations of the foliage area measurements. Solid circles with error bar are the means and standard deviations of the foliage area measured at different heights at a single location in the forest on August 26, 1992. The solid smooth curve is the corresponding fit of the mean data to the Weibull cumulative distribution function (eqn. 1). Symbols and dashed line in the insert shows the variations of the leaf area index with solar zenith angle.

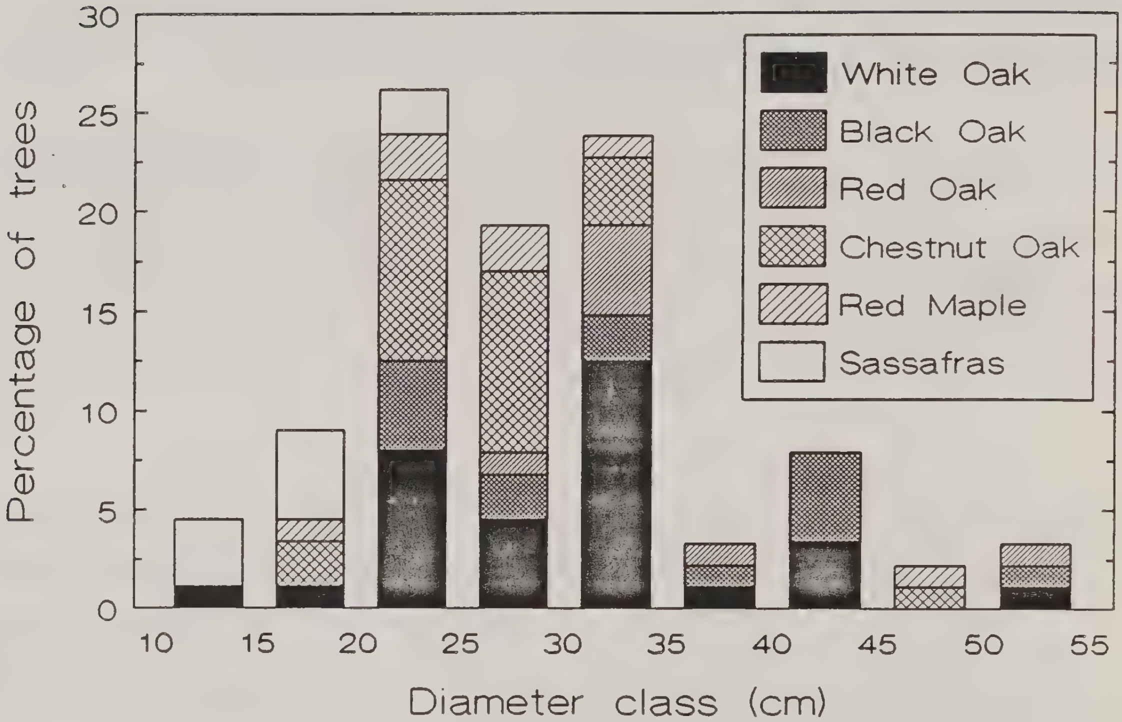
Fig. 4. UVB, PAR, and global transmission functions within the defoliated/refoliated hardwood forest. Data are averages over replicates and locations taken on August 25, 1992.

Fig. 5. Ratios of UVB to global (top), PAR to global (middle), and UVB to PAR (bottom) in relation with the cumulative leaf area index.

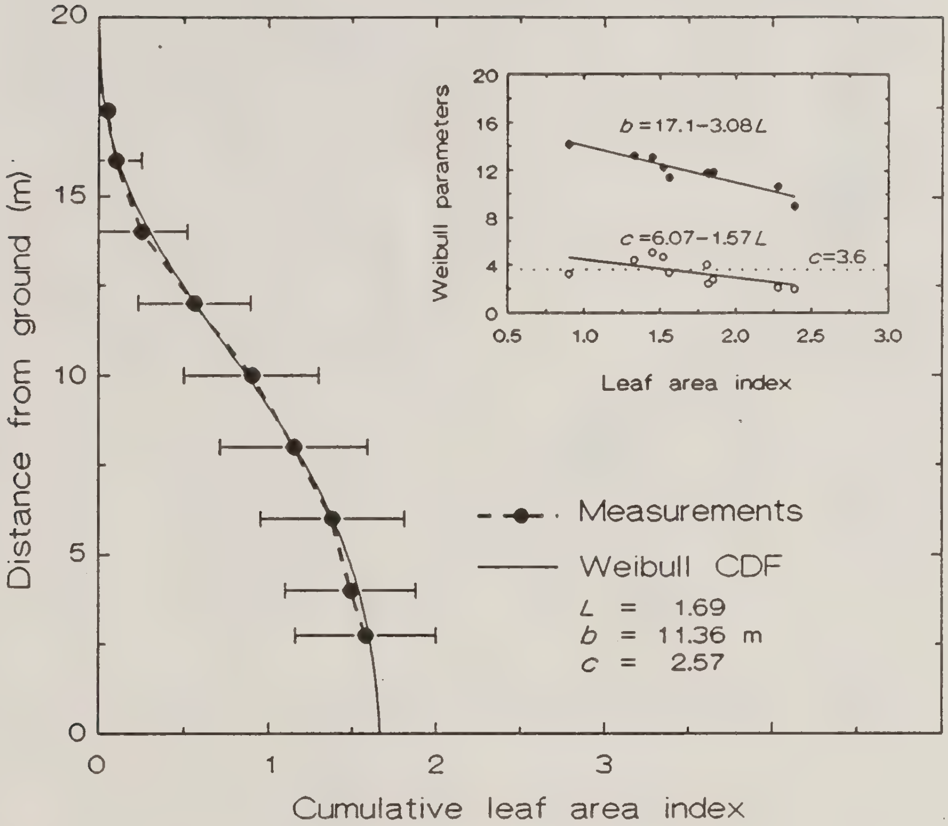
Fig. 6. Relationships between the logarithmic transforms of the canopy transmission functions for UVB (top), PAR (middle), and global radiation (bottom) and the cumulative leaf area index. Lines represent the corresponding linear regression equations. The slope of the regression lines yields the extinction coefficient in the Beer's law (eqn. 2).

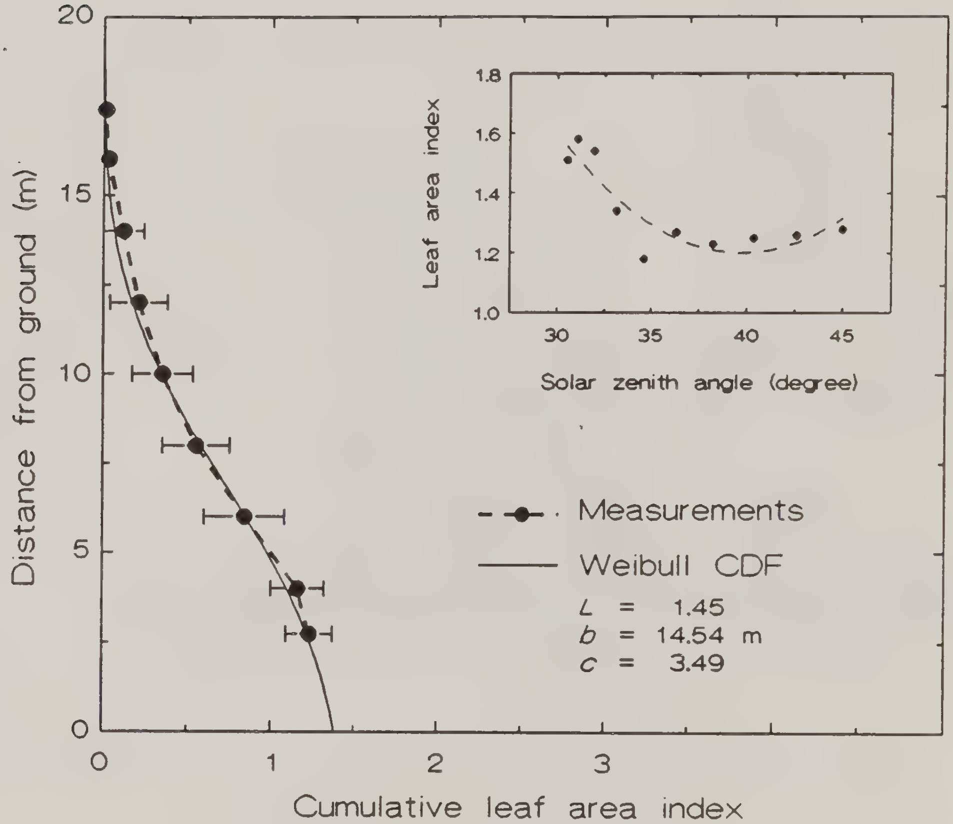
Fig. 7. Comparisons between predictions using Beer's law of attenuation (eqn. 2) and measurements of the transmission functions of UVB (left), PAR (middle), and global radiation

(right). Symbols and error bars are means and standard deviations of measurements. Lines are calculated using the Weibull parameters for the mean cumulative leaf area index (Fig. 2) and the extinction coefficients presented in Fig. 6.



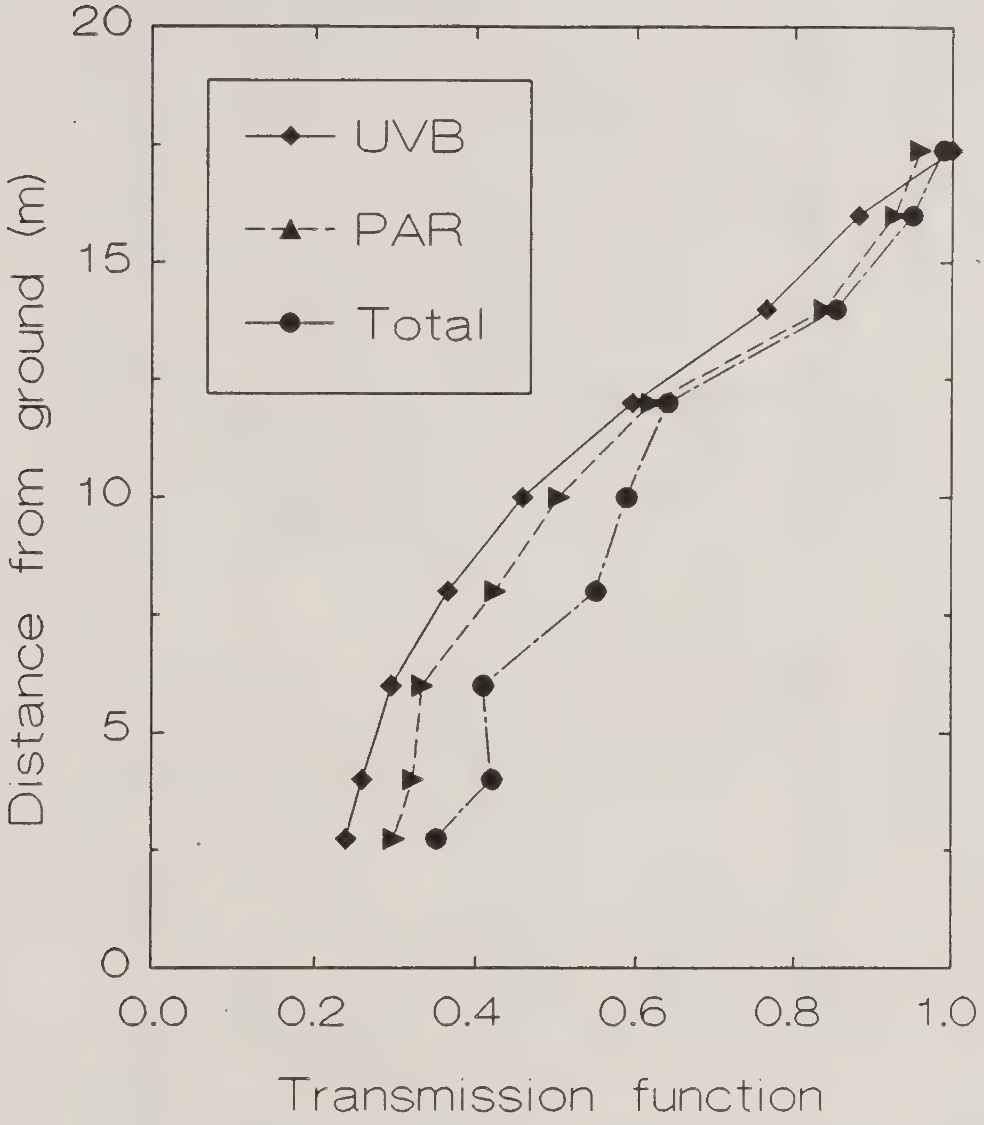
30
25
20
15
10
5
0
Percentage of trees
10
15
20
25
30
35
40
45
50
55
Diameter class (cm)
White Oak
Black Oak
Red Oak
Chestnut Oak
Red Maple
Sassafras


Distance from ground (m)
Cumulative leaf area index
Measurements
Weibull CDF
L = 1.69
b = 11.36 m
c = 2.57
Weibull parameters
Leaf area index
b =17.1−3.08L
c =6.07−1.57L
c=3.6

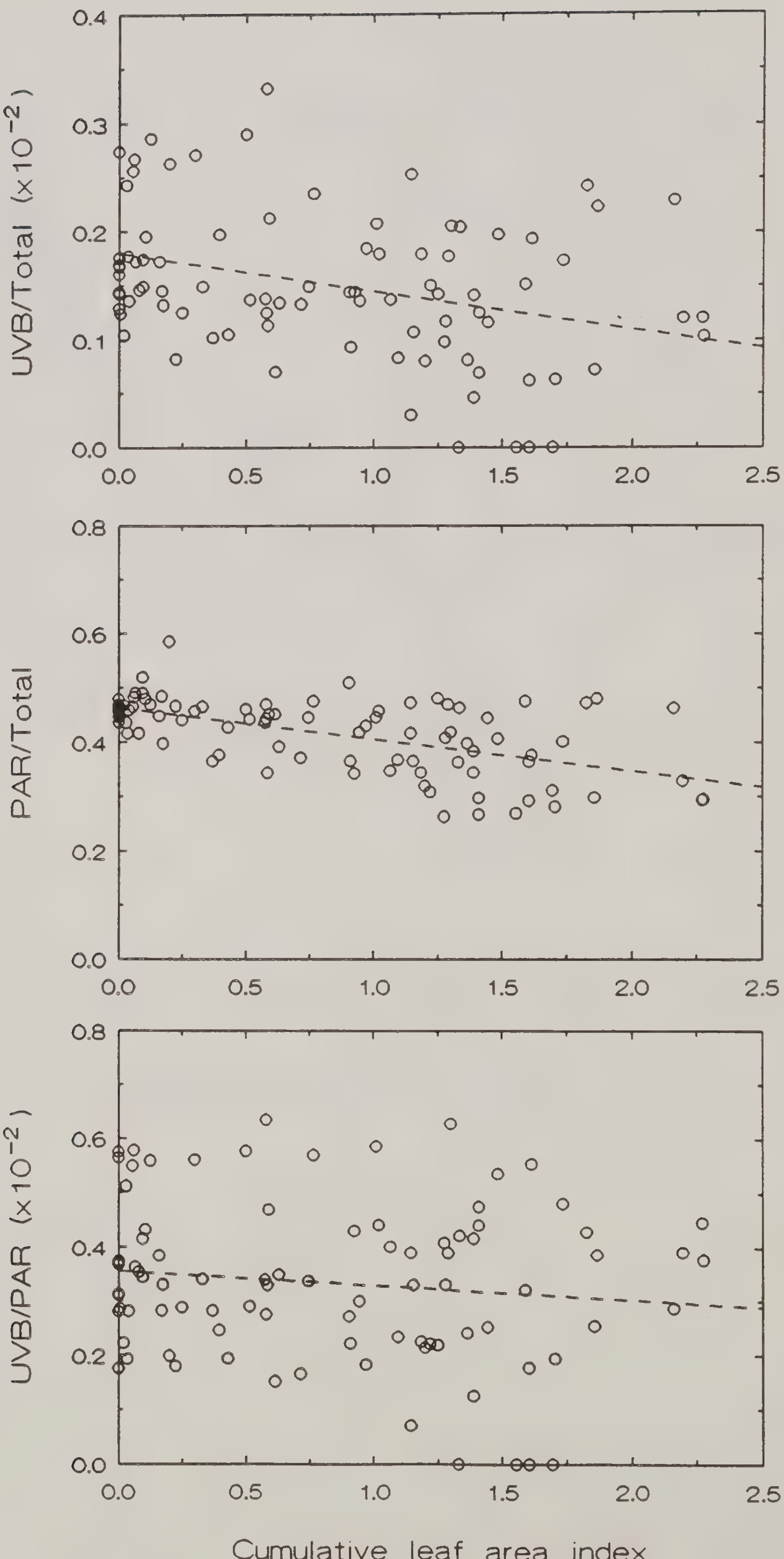


Leaf area index
1.8
1.6
1.4
1.2
1.0
30
35
40
45
Solar zenith angle (degree)
Distance from ground (m)
20
15
10
5
0
Measurements
Weibull CDF
L = 1.45
b = 14.54 m
c = 3.49
0
1
2
3
Cumulative leaf area index

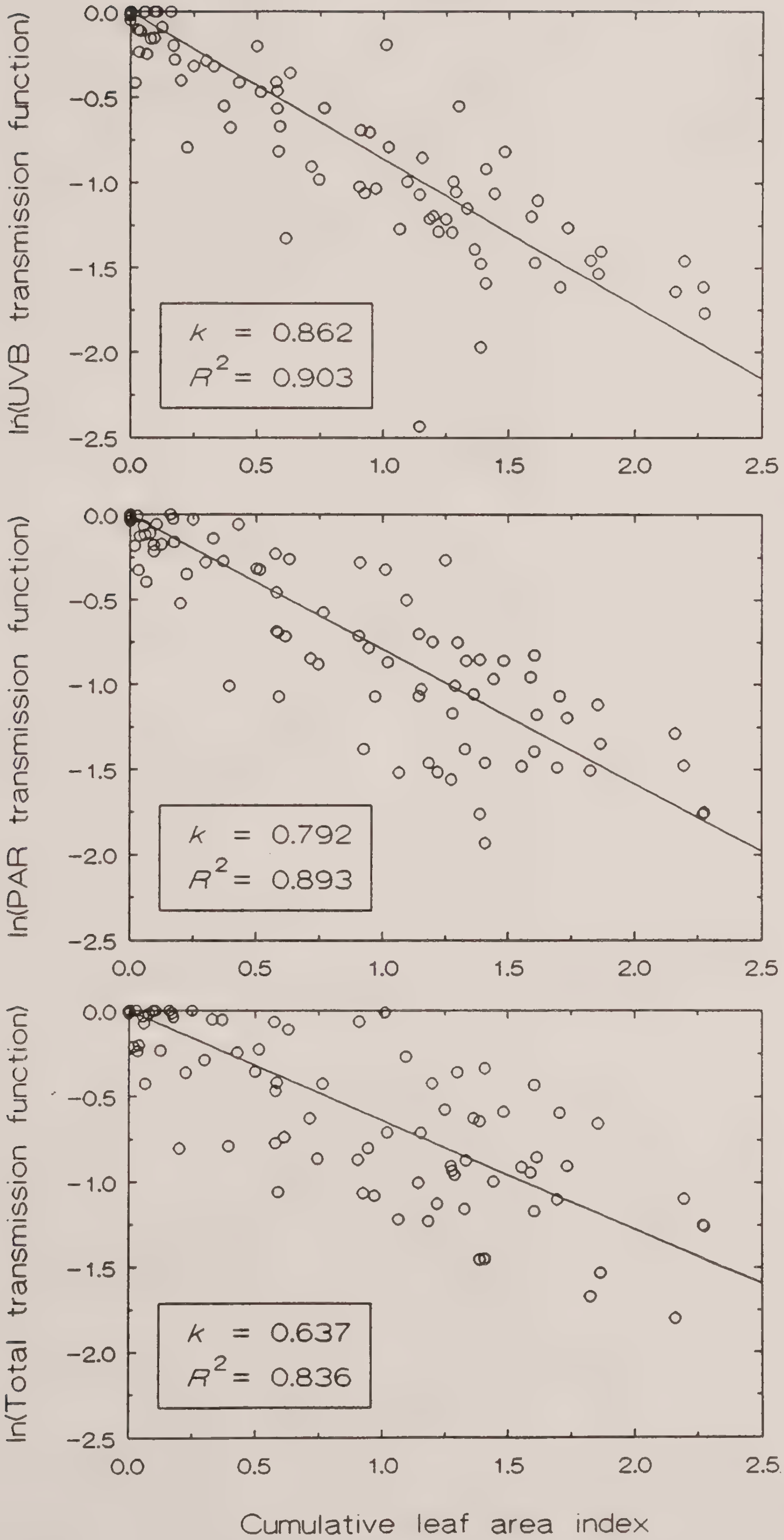
Yang et al., Fig.4



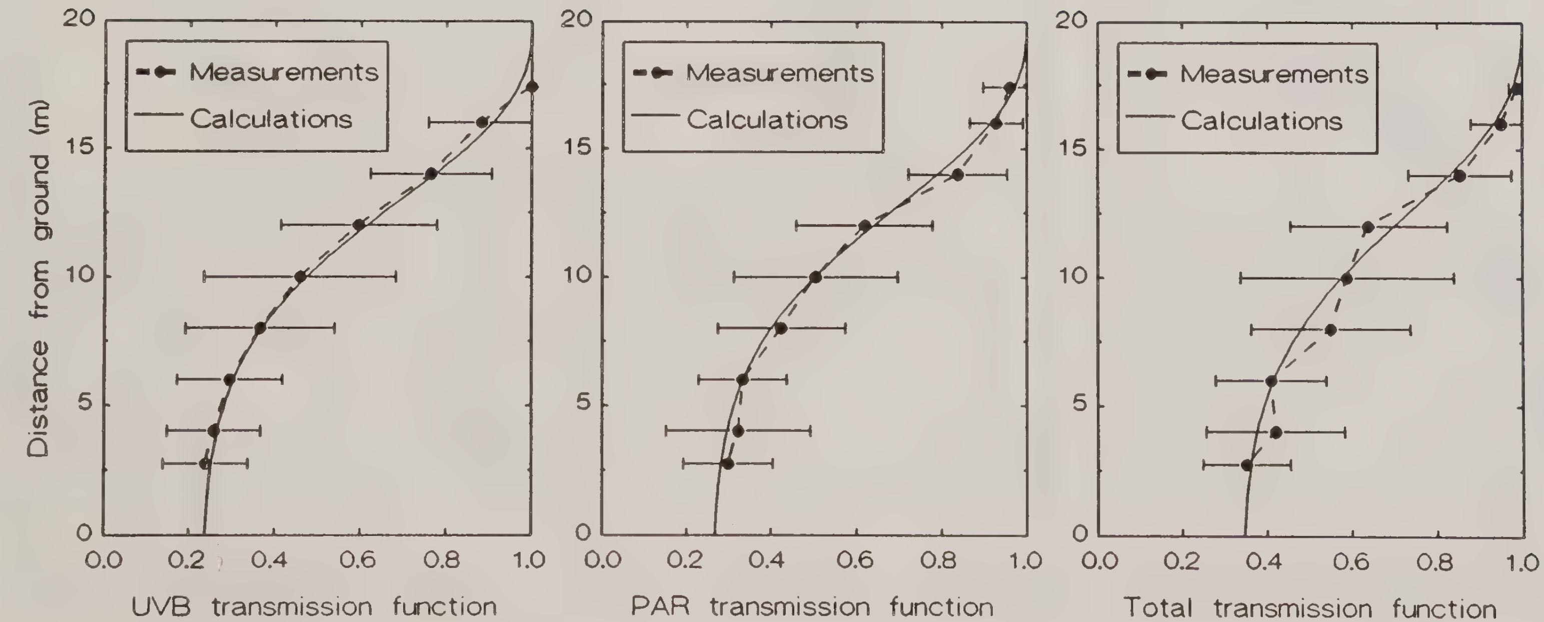
Yang et al., Fig.5



Yang et al., Fig.6



Yang et al., Fig.7



Milt Teske
Continuum Dynamics

National Spray Model Advisory Committee Meeting
Spokane: June 24-25, 1993

Suggested Topics for Further Model Development
Milton Teske, Continuum Dynamics, Inc.

Topics (not in any order):

Selective destruction of wing tip vortices -- different for upwind/downwind sides
Generic input data structure -- so that dataloggers, pathlinks, etc. can be loaded into model
Vertical flux profile downwind of near wake
More nozzles
"Go-no go" decision mechanism -- Terry Biery's annual request – need 486 on-board in aircraft
Hint book with sensitivity interpretation -- this is a very good idea from Bob Sanderson
Discrete canopy -- Jim Rafferty still thinks this is impossible
Collection efficiency -- historical document and standardization
Technology transfer to the aerial applicator -- you and I know this is difficult
NEFEC coordination of experiments -- perhaps a clearinghouse could be Pat's job
Lidar followup -- we need to understand what we have before commiting more money
Extend models to complex terrain -- this next year we should just exercise VALDRIFT
Swath widths -- how to get people to do it in crosswind -- publish all aircraft results
Expert system interface -- we should see what GypsES will get us
Make the program "faster" -- optomize run time
Airblast sprayers -- SDTF will do this -- you need assurances that FS will get a copy
Vector control -- knowing exactly where the aircraft is -- what can we do?
Updated training -- will Marana be a good place for a two-day "refresher" course
Instrumentation overview for spraying -- Harold could get into this
Shelter belts and buffer zones
Data recall -- keep a log of all previous FSCBG runs and major results -- disk space!
Licor validation -- Miller has data and will send to me, but we may need a field test
Sample in the vertical in canyons
Volume source model implementation into FSCBG

Summary

Status of the Models

Publications

New Modeling Features

Unsolved Mysteries

Other Topics

Status of the Models

FSCBG

4.1 released with return questionnaire in December 1992
4.2 released with newsletter notice in April 1993

New Features:

- Data export to commercial graphics packages
- DOS operating system interface for file names
- Interactive libraries
- Separate mass size library entries for small drop sizes
- Mass size distribution manipulation
- Evaluation of swath width
- Calculation of total accountancy of released material
- Pie and bar charts to display total accountancy results
- Font selection for graphical output
- Saving plotting parameters
- Collection efficiency added to discrete receptors
- Net radiation index computation

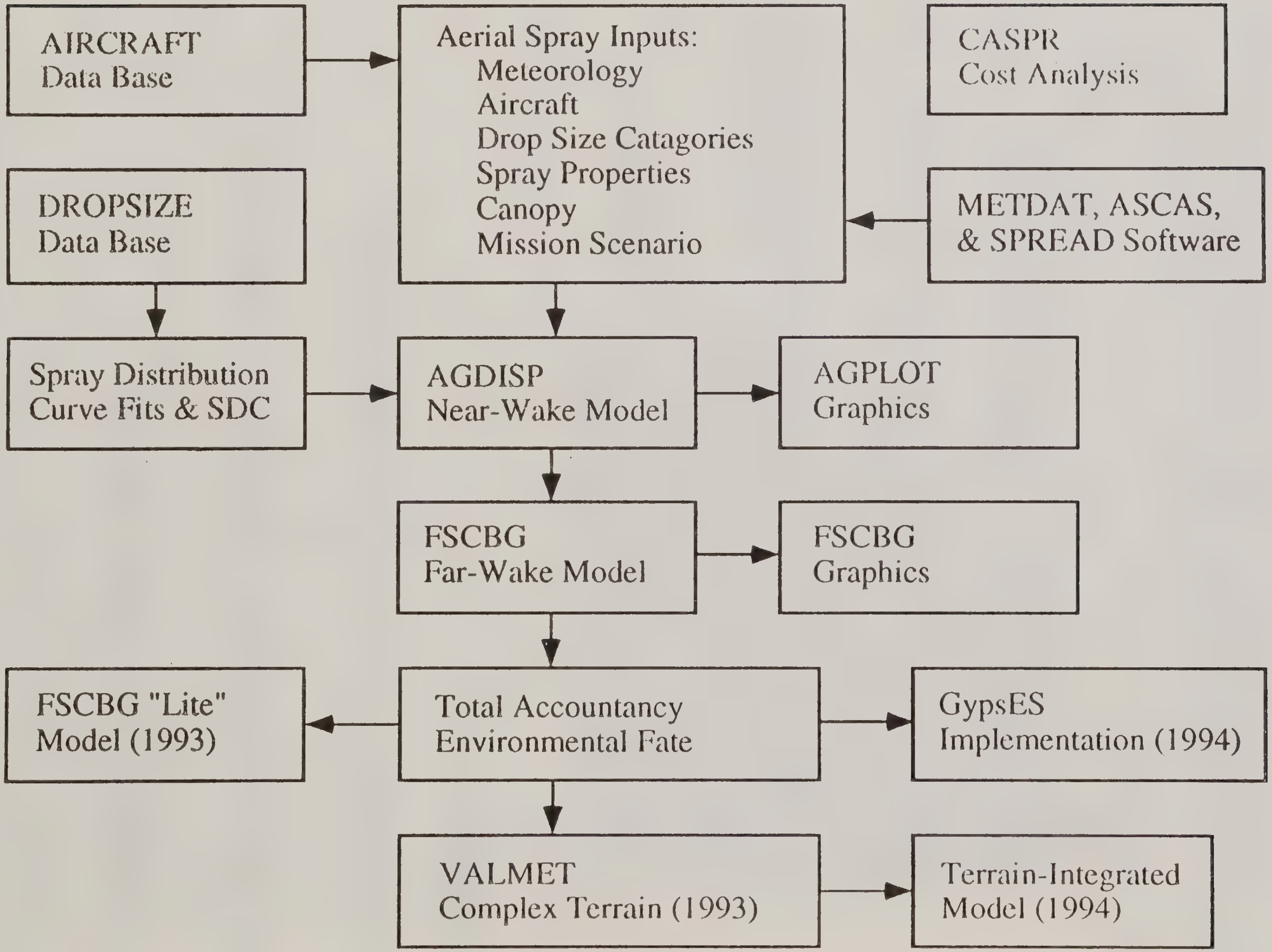
AGDISP

6.0 Maturity -- much as its principal supporter

User Group Count: 42 AGDISP and 70 FSCBG

Newsletter #4: the biggest one yet!

The Compleat Enchilada



3

1993 Publications

Curbishley, T. B., M. E. Teske and J. W. Barry. Validation of the CASPR spray aircraft efficiency model. *Applied Engineering in Agriculture* 9(2):199-203.

Teske, M. E. and J. W. Barry. Parametric sensitivity in aerial application. *Transactions of the ASAE* 36(1):27-33.

Teske, M. E., A. J. Bilanin and J. W. Barry. Decay of aircraft vortices near the ground. *AIAA Journal* (to appear).

Teske, M. E., J. F. Bowers, J. E. Rafferty and J. W. Barry. FSCBG: an aerial spray dispersion model for predicting the fate of released material behind aircraft. *Environmental Toxicology and Chemistry* 12(3):453-464.

Teske, M. E. and J. W. Barry. Validation of the aerial spray dispersion model FSCBG. *Transactions of the ASAE* (in preparation).

Teske, M. E. and J. W. Barry. Aerial spray modeling. Environmental Modeling: Volume II (in preparation).

Teske, M. E., A. J. Bilanin ~~and J. W. Barry~~. Drop size scaling analysis of non-Newtonian fluids. *Atomization and Sprays* (in preparation).

New FSCBG Features

Anticipated release of FSCBG 4.3 in Fall 1993, automatically to all users responding to the questionnaire. Its new features will include:

On-Line Help
Near-Wake Enhancements
SprayMaze

On-Line Help

```
Menu>
? help  <esc> go back  <return> select current
```

Help is really going to happen:

Context sensitive
Fully indexed
Layered
Optimized search engine

Combining the User Manual, One-on-One Manual, and Training Session material, with all new program features added.

You will never have to read paper documentation again!

Near-Wake Enhancements

We have finished a detailed examination of FSCBG predictions in significant downwind drift situations. Our findings suggest:

1. The development of a clear definition of the near-wake of an aircraft, and the hand-off of model calculations from the near-wake model (solving Lagrangian equations for the spray trajectories) to the far-wake model (solving Gaussian equations for the dispersion).

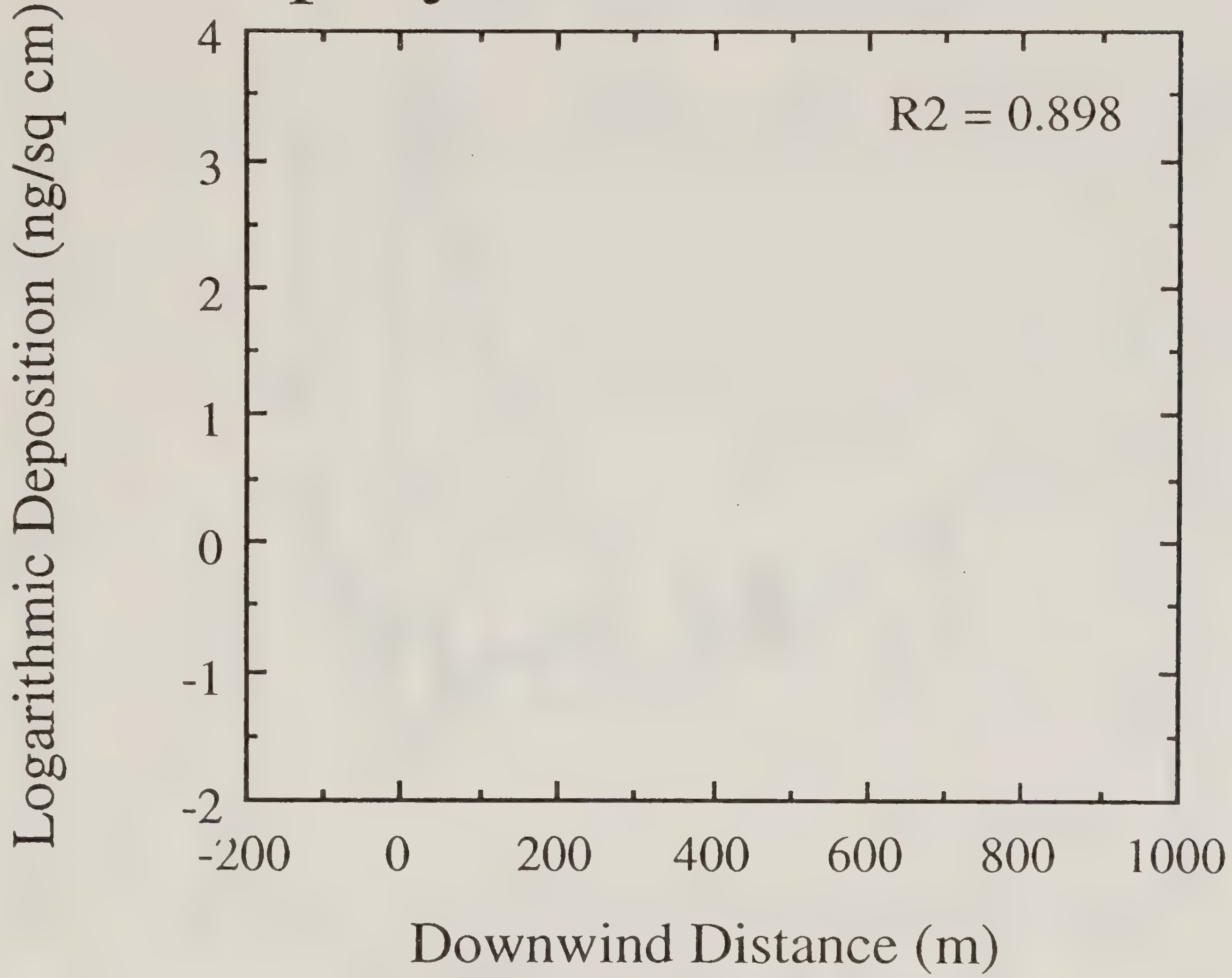
2. The development of a clear relationship between downwind dispersion and aircraft release height, and the consequences evident in deposition at large distances downwind.

3. The realization that drop size distributions must be resolved with categories far greater than previously anticipated.

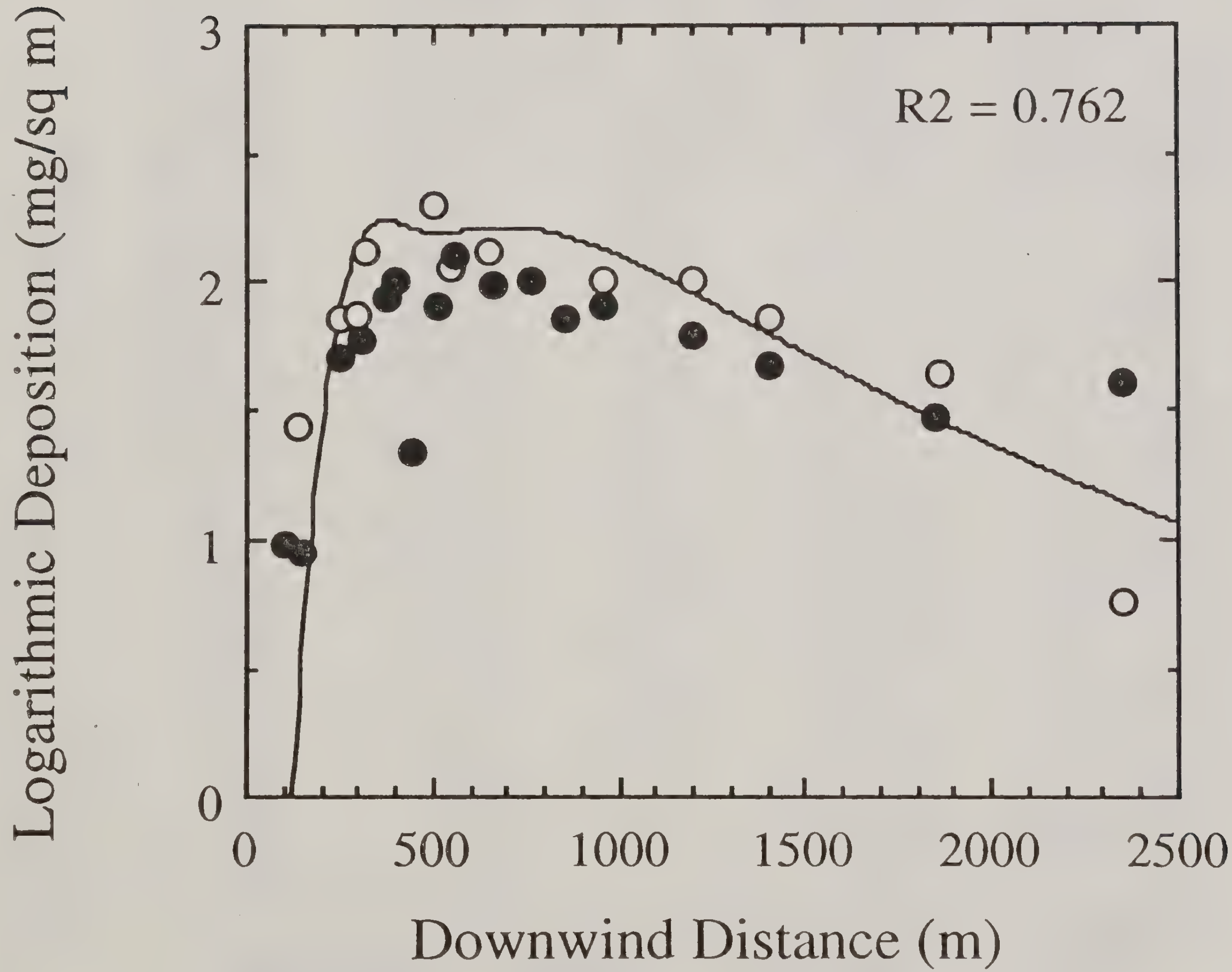
4. The demand, as always, for accurate meteorological, aircraft, and deposition field measurements before attempting serious model comparisons.

* Smaller drop sizes must be included (to 10 microns)
* No mass fraction greater than two percent
* All nozzles in the simulation

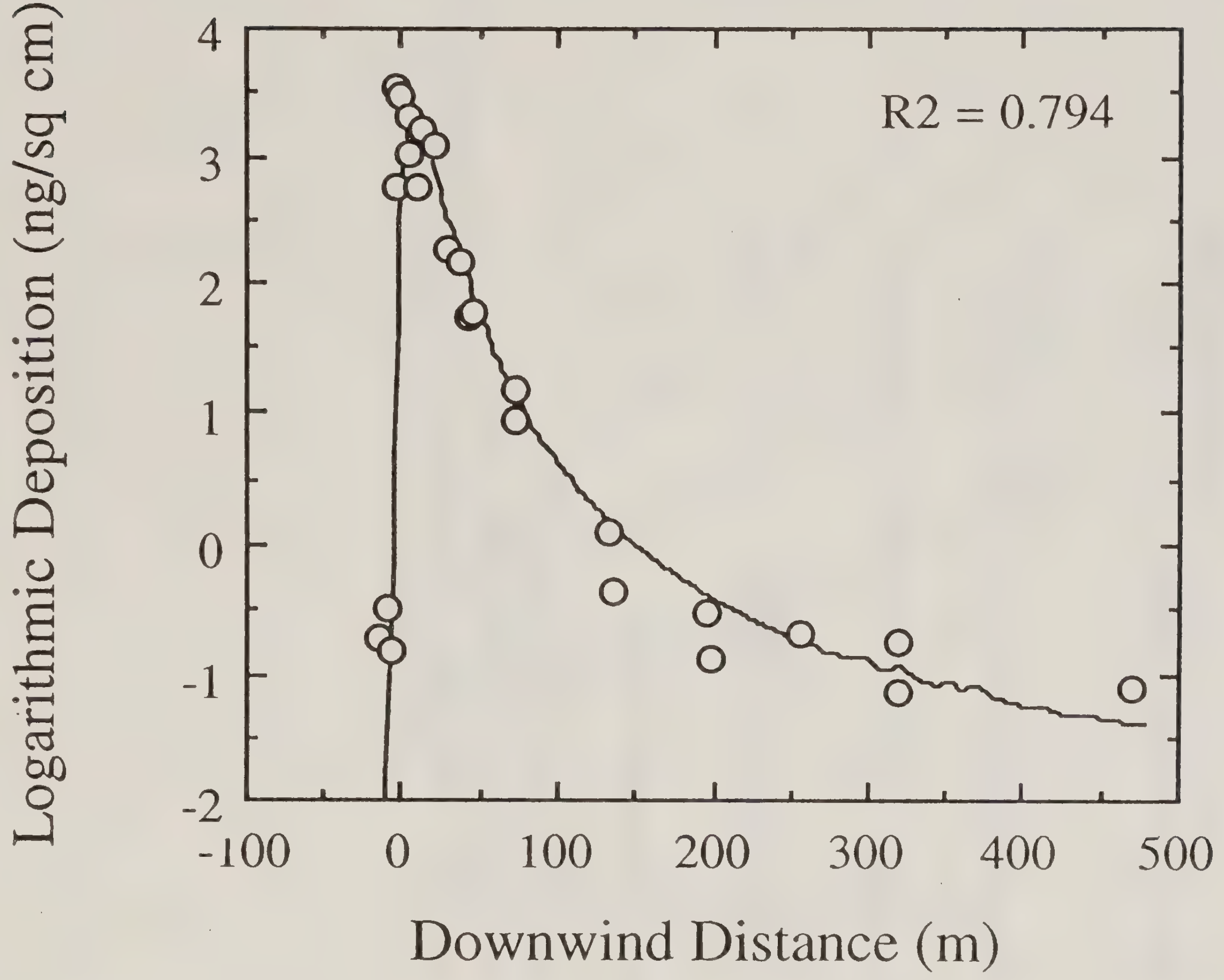
Spray Drift Task Force



Program WIND



Dow Elanco B



R2 = 0.794
Logarithmic Deposition (ng/sq cm)
4
3
2
1
0
-1
-2
-100
0
100
200
300
400
500
Downwind Distance (m)

Non-Newtonian Effects

We have completed an examination of non-Newtonian effects in the USDA Forest Service drop size distribution data base. Our results suggest that the critical parameters:

$$Re = \text{Reynolds Number} = \frac{\rho\,(U_\infty - U_j)\,D_j}{\mu}$$

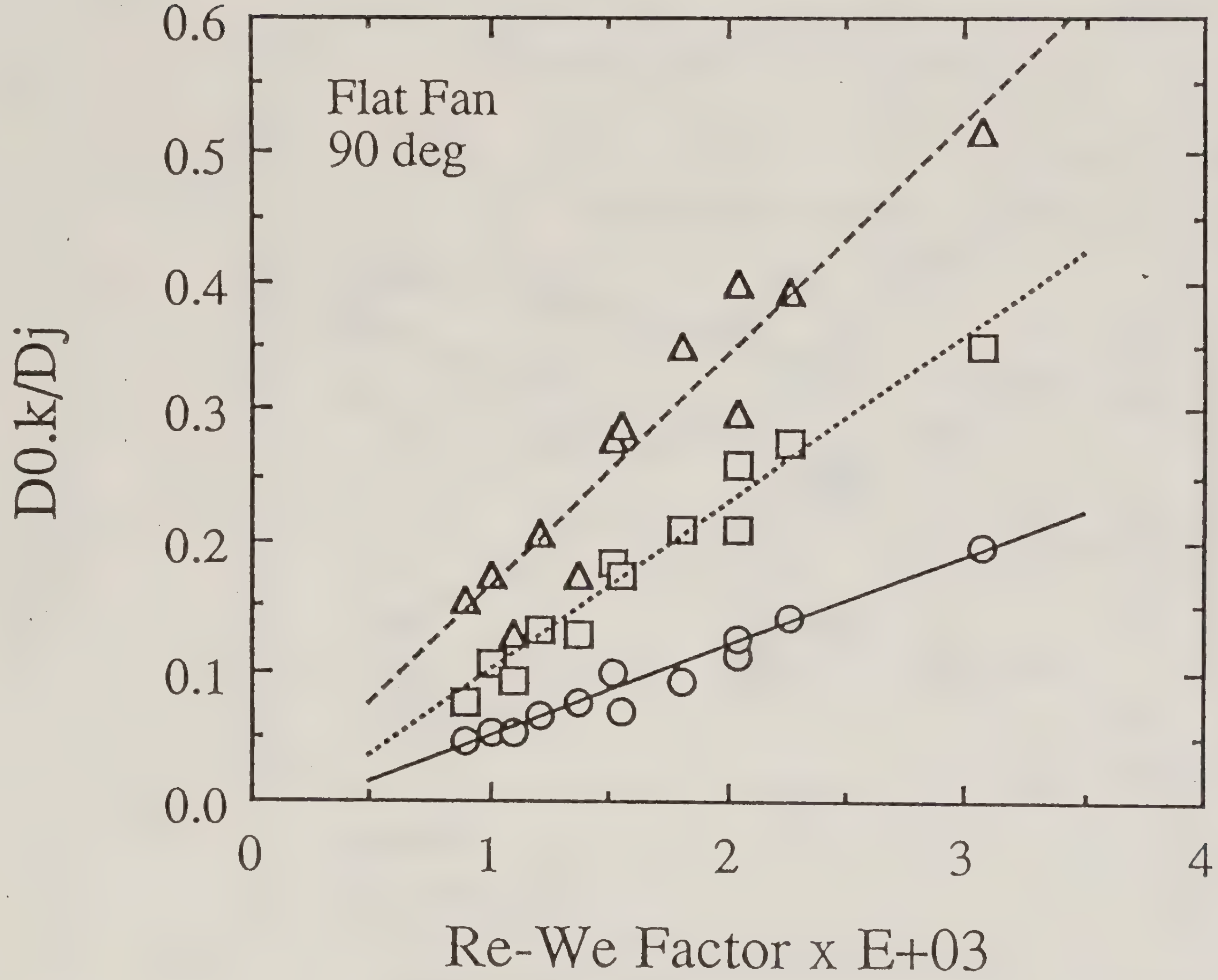
$$We = \text{Weber Number} = \frac{\rho\,(U_\infty - U_j)^2\,D_j}{\sigma}$$

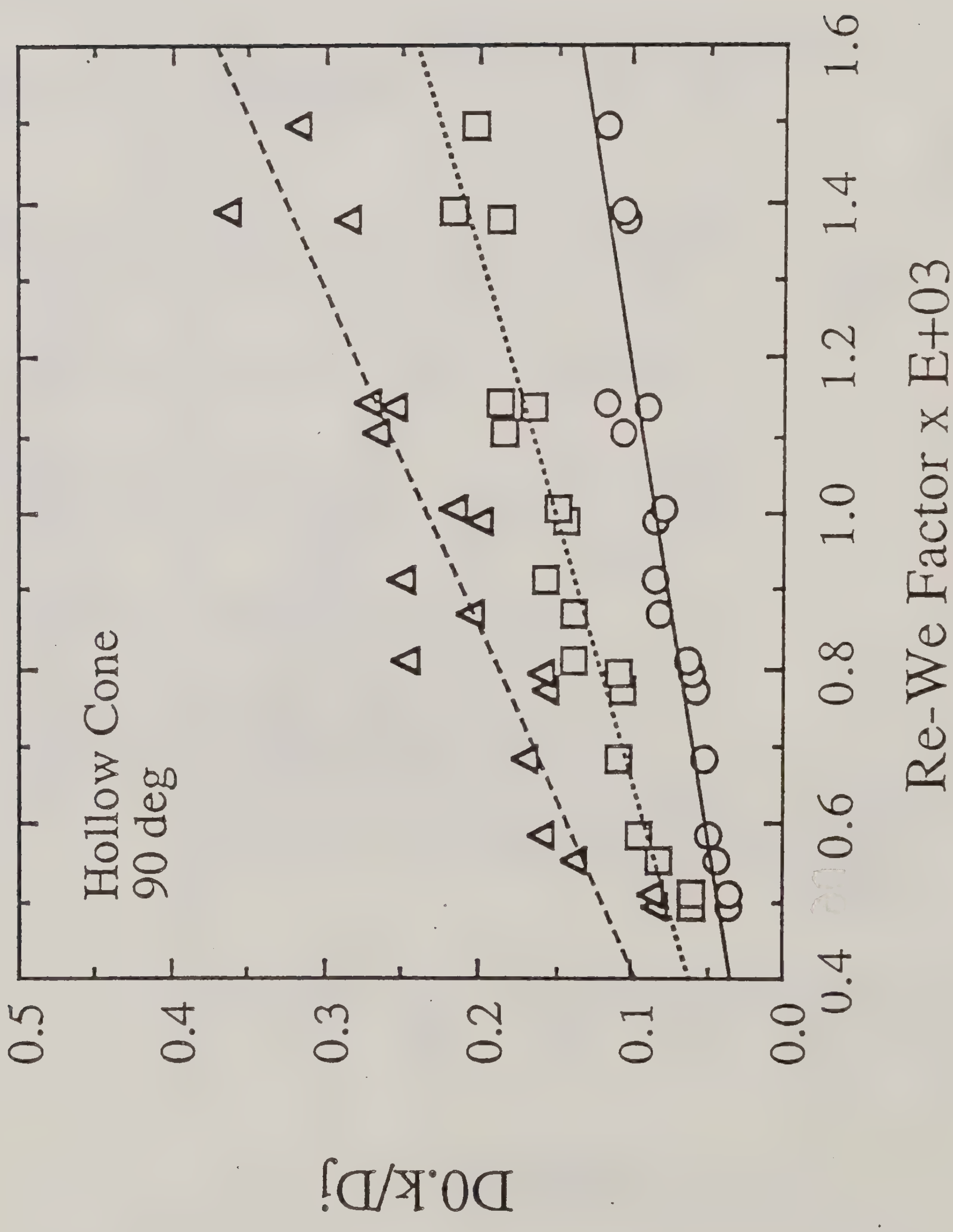
can be implemented into a best-fit equation:

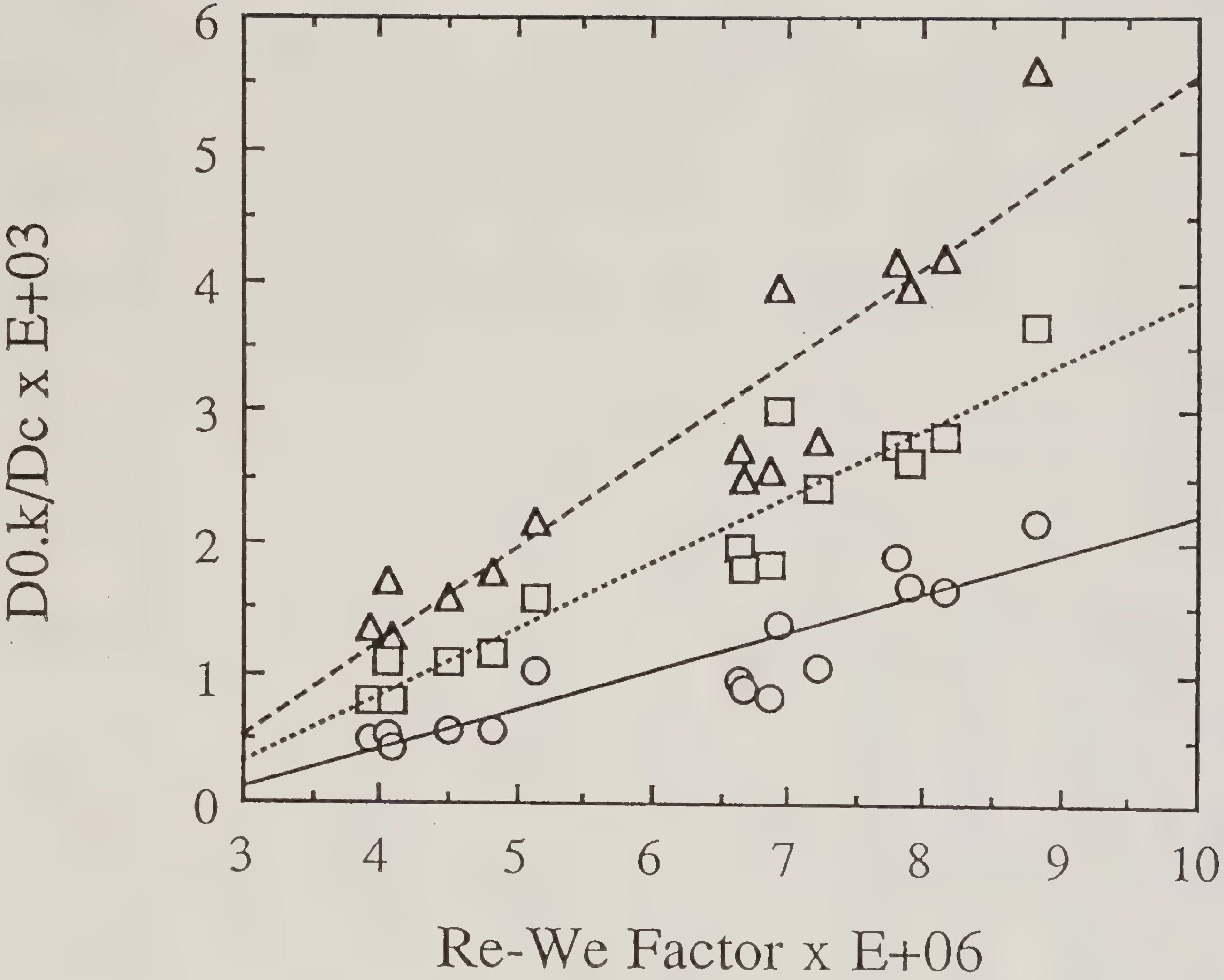
$$\frac{D_{0.k}}{D_j} = A_k + B_k\,\frac{We^c}{Re}$$

where least-squares finds:

$c = 0.42$ for flat fan nozzles
$c = 0.38$ for hollow cone nozzles
$c = 0.23$ for rotary atomizers (with an inverse square root function on cage rotation rate)


Flat Fan
90 deg
D0.k/Dj
Re-We Factor x E+03
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4


Hollow Cone
90 deg
D0.k/Dj
Re-We Factor x E+03
0.0
0.1
0.2
0.3
0.4
0.5
0.4
0.6
0.8
1.0
1.2
1.4
1.6


D0.k/Dc x E+03
Re-We Factor x E+06
0
1
2
3
4
5
6
3
4
5
6
7
8
9
10

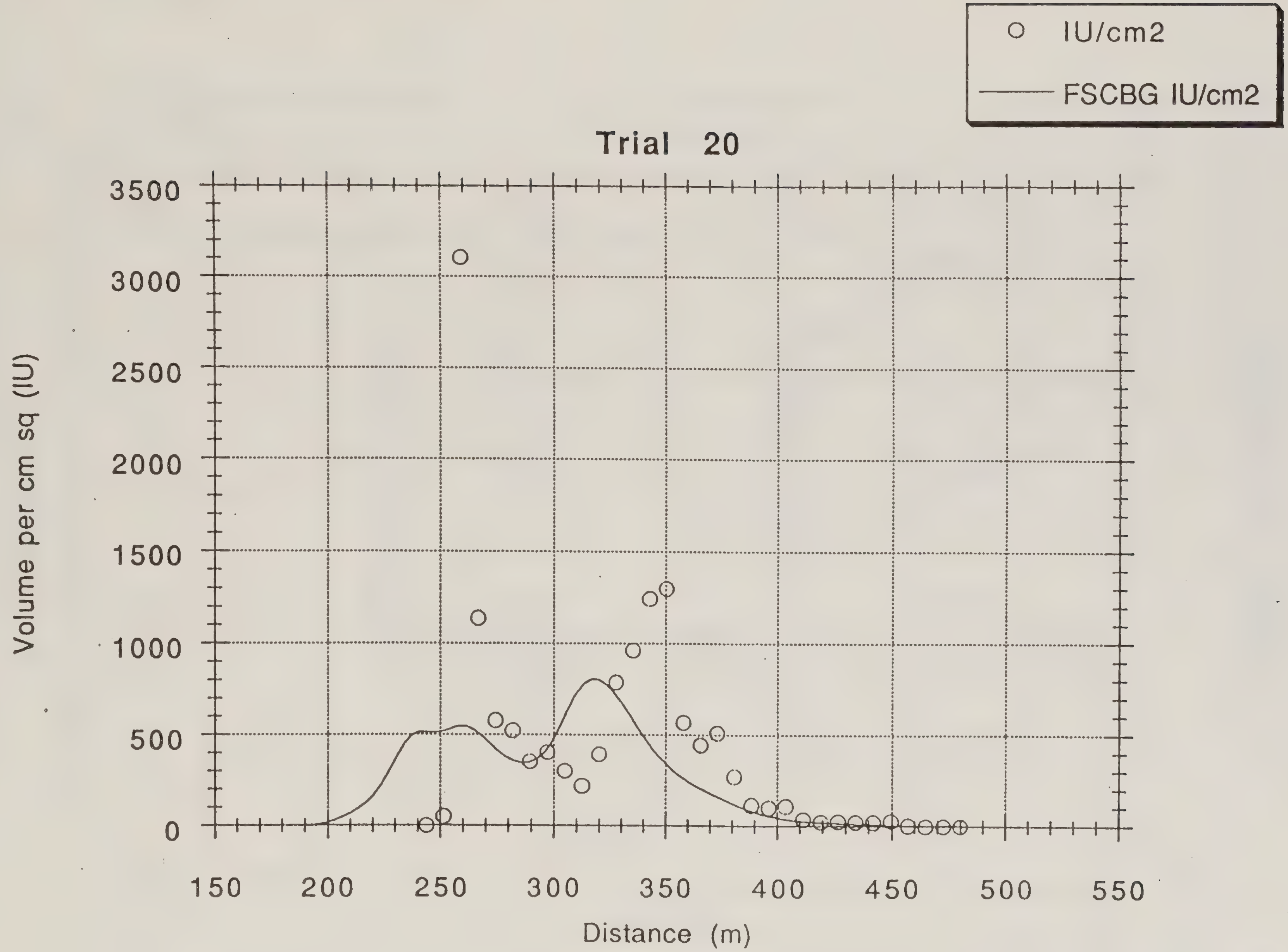
Validation

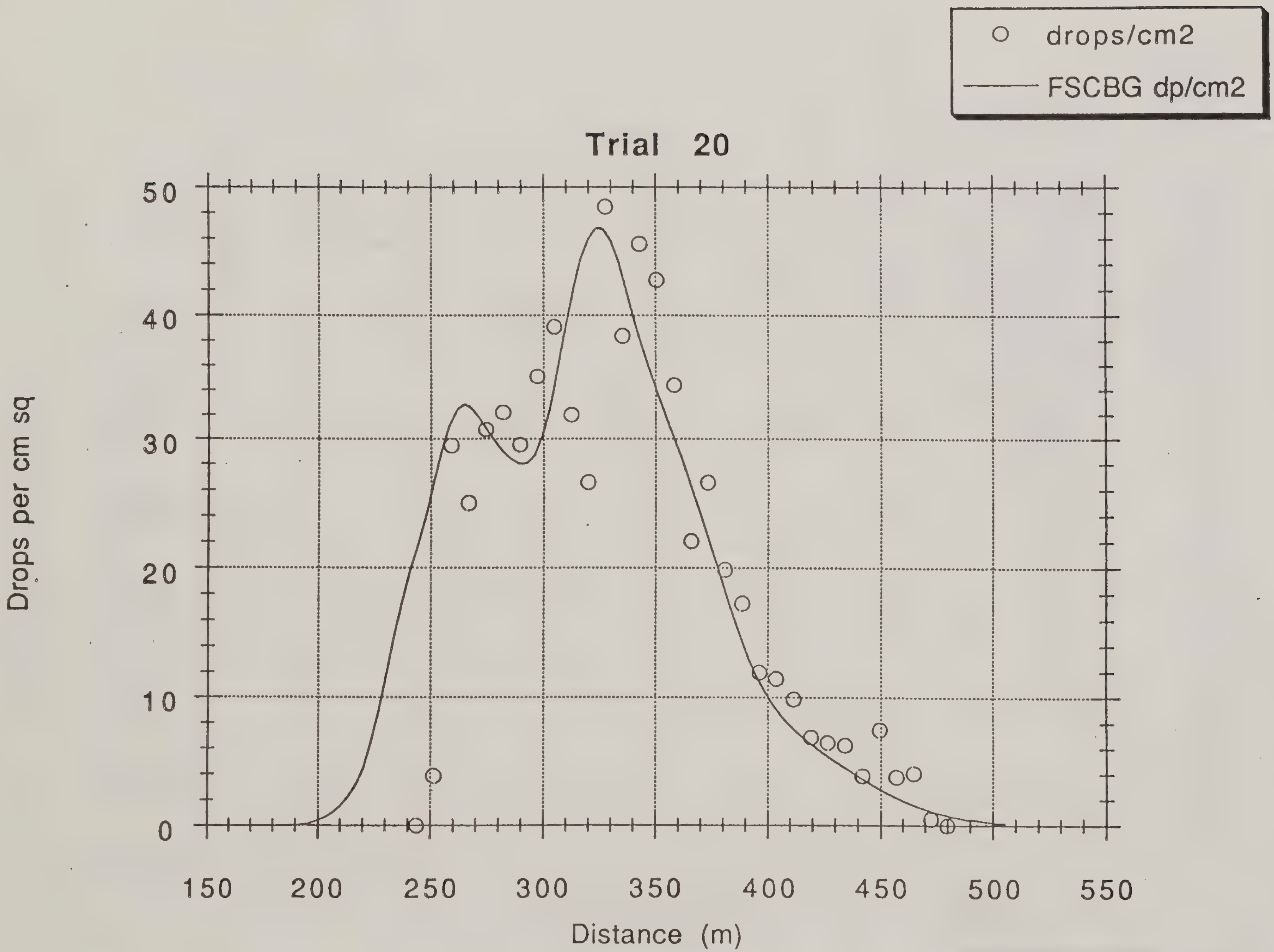
We are in the process of examining old data sets to compare with FSCBG:

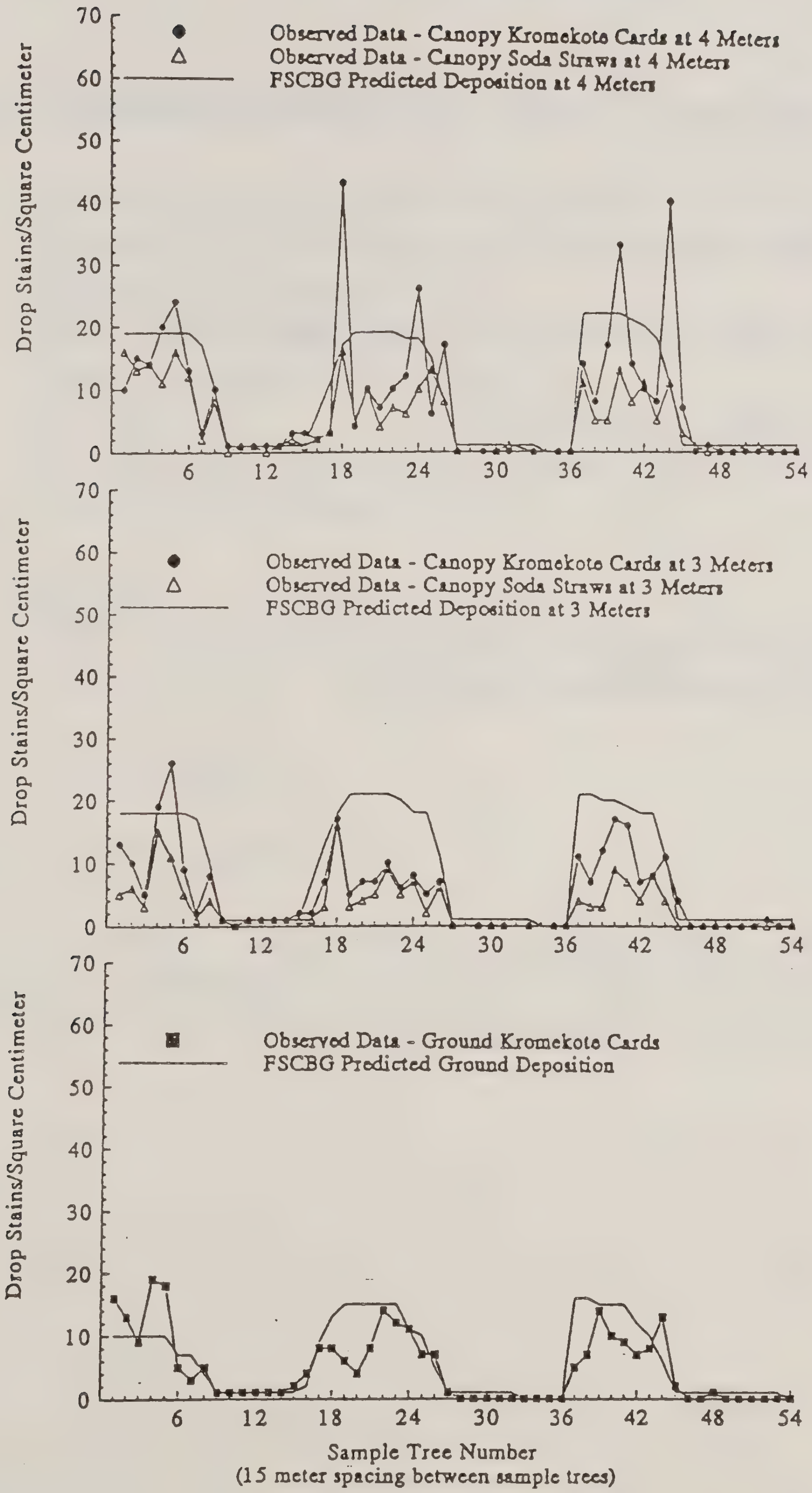
C-130 Trials 1990
Davis Characterization Trials 1988
Davis Virus Trials 1991
Rennic Creek 1974

in addition to current work on:

Almond Tree Canopy


Trial 20
IU/cm2
FSCBG IU/cm2
Volume per cm sq (IU)
3500
3000
2500
2000
1500
1000
500
0
150
200
250
300
350
400
450
500
550
Distance (m)


Trial 20
drops/cm2
FSCBG dp/cm2
Drops per cm sq
50
40
30
20
10
0
150
200
250
300
350
400
450
500
550
Distance (m)


70
60
50
40
30
20
10
0
Drop Stains/Square Centimeter
Observed Data - Canopy Kromekote Cards at 4 Meters
Observed Data - Canopy Soda Straws at 4 Meters
FSCBG Predicted Deposition at 4 Meters
6 12 18 24 30 36 42 48 54
Observed Data - Canopy Kromekote Cards at 3 Meters
Observed Data - Canopy Soda Straws at 3 Meters
FSCBG Predicted Deposition at 3 Meters
Observed Data - Ground Kromekote Cards
FSCBG Predicted Ground Deposition
Sample Tree Number
(15 meter spacing between sample trees)

Problems

It's not all fun and games. Some of the unsolved FSCBG problems are:

Along-wind flight lines

Flight line edge effects (turning the flight lines on and off)

Canopy top deposition and turbulence

But:

We know users are using the model, and they haven't called us very often with gummi-bear questions.

Other Topics

Other anticipated tasks:

Property estimation for evaporation modeling
Statistically averaged quantification
Further validation studies
Non-parallel flight lines
Implementation of VALMET
FSCBG "lite"
Spread factor technology (ASME Fort Worth)
Visit to New Zealand 1993

GypsES

Swath widths

User Group Support

Spray Drift Task Force

U. S. Air Force Fuel Jettisoning contract: Phase II to develop the drop size distribution for fuel from 2-in ports at 500 mph, along with a multi-component evaporation model

Bob Mickle
Environment Canada

February 22, 1993

To: Jack Barry JB 2-23-93

From: Bob Mickle

Re: Input to WEEDWORKS '93 Talk

Jack, some thoughts on where we are intending to use models in Canada in order to assist in the registration of pesticides, estimate buffer zones for environmental protection of sensitive ecosystems and potentially assess a spray program by combining onboard monitoring of spray parameters with model predictions of spray fate.

Back in 1989, an Interdepartmental Task Force was assembled to develop a generic approach for assessing spray drift as input to the registration of new pesticides. The conceptual framework for the required data requirements and review process is given in Figure 1. Fundamental to this approach was the assessment of drift potential for a particular pesticide given the proposed use strategy for the pesticide of interest. Because of the unlimited combinations of formulations/ application techniques etc., a generic approach was developed (Figure 2) which ultimately would rely on models as the tool for predicting the potential for off target movement of the pesticide. Coupled with the toxicological information, an estimate of environmental impact could be calculated. If,using this technique, the model/ toxicology results indicated a potential for significant environmental impact, then further specific information would be required in support of the registration. In order to be able to use the models, first an evaluation of the model against field data was required (ie Figure 3). Within Canada, we have spent the last couple of years developing a data base which can be used for model verification. Presently, it has a select number of field experiments included in the data base, but we are intending to release it to the general scientific community in hopes that each group will take the time to update their part of the data base. The combined data sets will then be reincorporated into the total data base. Each contributor would then receive the full data base. Confidential input would remain the property of the contributor and would be held separate from the public domain data. This is presently being carried out under

contract with RPC in New Brunswick. This data base will then be used to further validate a number of models. As Figure 3 shows, once a model has been validated then it can be used to optimize sprays, to assess potential impacts of new pesticides as part of the registration process and help in setting buffer zones around sensitive areas. At present, I'm developing a generic approach to setting buffer zones based on actual field data. The next step will be to use a similar approach with the models to see how consistent the model approach is with the field data approach.

The other area where we are looking to use models is for a quick assessment of a just completed spray program. Recently, we began to instrument aircraft with a monitor to record various spray parameters (Figure 4) including aircraft height (radar altimeter), flow, ground speed (used to calculate line source strength), boom pressure, rotary atomizer rpm (used to determine emission spectrum), ambient temperature and relative humidity (used to calculate potential for evaporation) and GPS/Loran (used to track actual spray line). All of these parameters can be used as input to FSCBG along with tower wind speed (using aircraft and ground speed, heading and track an estimate of wind speed and direction can be determined from the aircraft data) to predict the on target deposit and off target drift. In particular, the on target deposit data could be used to assess the spray deposit uniformity and hence to evaluate the need to do an immediate respray as required.

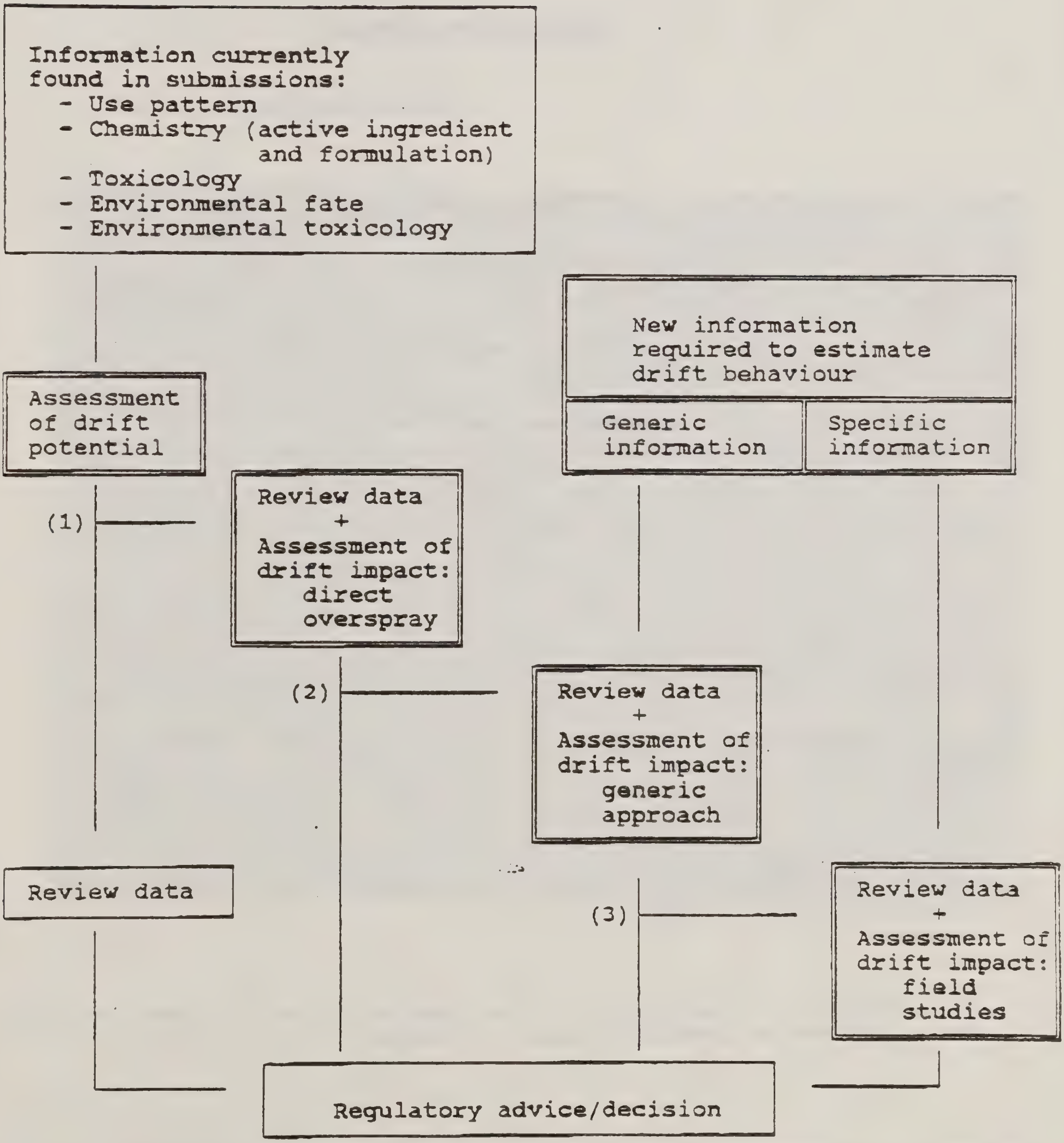


Figure 1. Proposed conceptual framework for data requirements and review process related to pesticide drift. The double boxes are added to the current registration process. The numbers in parentheses refer to decisions discussed in the text.

APPENDIX A

PESTICIDE IMPACT REVIEW

EMISSION SPECTRUM

Drift (100-150 Microns)

- % of emitted/evaporated volume
- volatile/non-volatile fraction
- emission height
- Meteorology (worse case scenario

Deposit (>150 Microns)

- Flightline offset
- vapour drift

Model

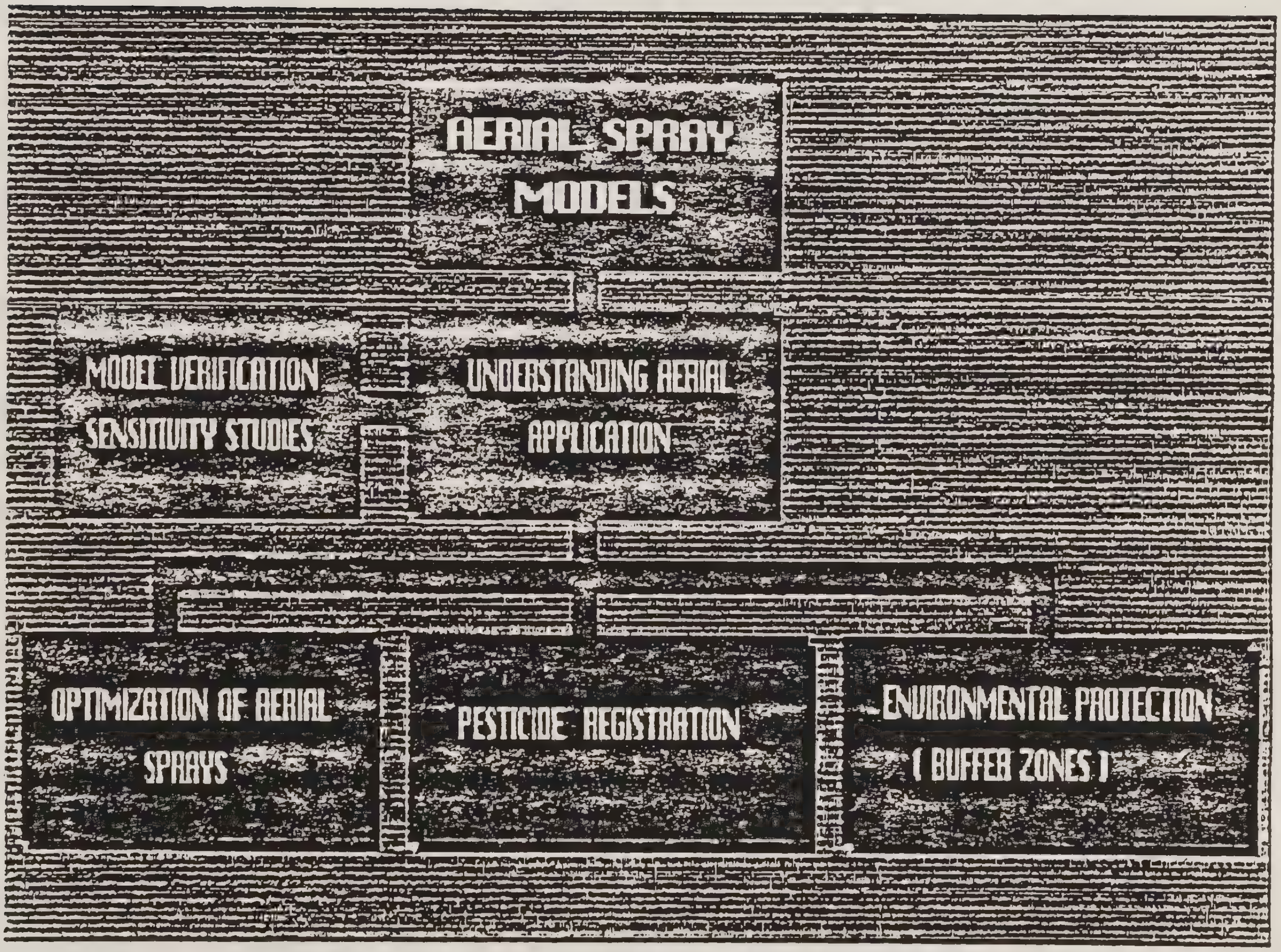
Data Base

Deposit/concentration/dosage as a function of downwind distance

Application Rate
Deposit Surface (wet/dry)
Persistance
Toxicity

Buffer zone requirements to protect sensitive biological receptor

* Drift refers to airborne droplets less than 150 microns which move away from the target zone and eventually deposit off-target.


AERIAL SPRAY MODELS
MODEL VERIFICATION SENSITIVITY STUDIES
UNDERSTANDING AERIAL APPLICATION
OPTIMIZATION OF AERIAL SPRAYS
PESTICIDE REGISTRATION
ENVIRONMENTAL PROTECTION (BUFFER ZONES)

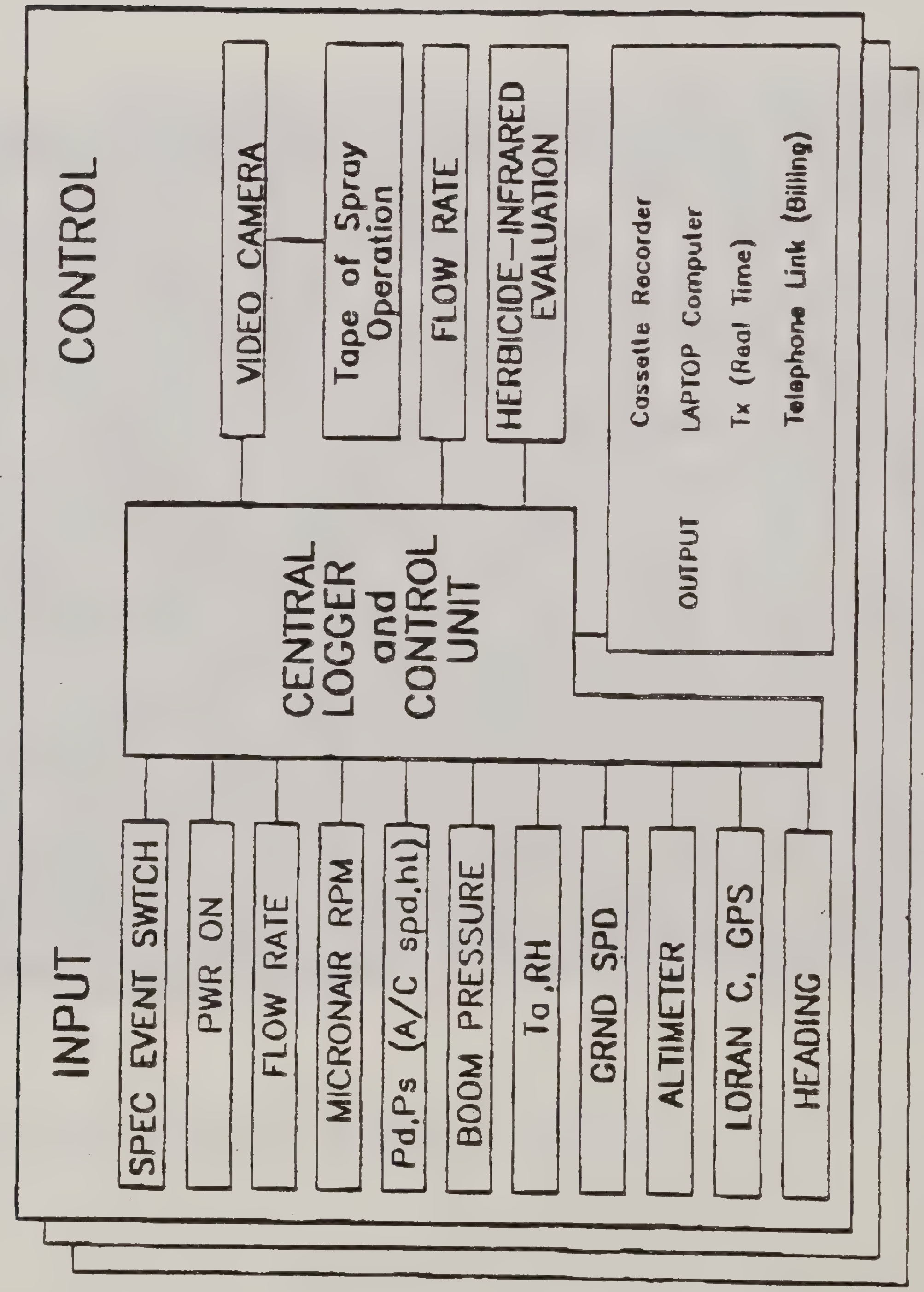


Figure 5. Future Additions to the Aircraft Spray Monitor

Fig 4

June 29, 1993

To: Pat Skyler
USDA Forest Service

From: Bob Mickle
AES

Re: Modeling Committee Meeting - June 23-24, 1993
Below is the information requested from the Spokane Meeting.

1)Review of AES work in Canada

Over the past year, the Interdepartmental Task Force on Spray Drift has developed a data base that could be used in model evaluation or sensitivity analyses of operational parameters on deposit and drift. Presently, the data base (d-Base IV) contains information from 48 references in a total of 227 subsets. Routines have been developed for extracting deposit and drift tables in tabular form for import into statistical or graphical software packages. Data can be exported to files corresponding to individual reference sources or can be appended to files containing several reference sources. In the near future, the data base will be forwarded to original contributors and other interested parties (contact Bob Mickle if you are interested in receiving a free copy). We are hoping that individuals will add their additional data sets to the data base and return the updated version to RPC. An updated version with input from all contributors will then be returned to the respondents. Confidential data sets will be restricted to the contributor. Ultimately, these data will be used in the selection of a model to be used in the registration and regulation of pesticides.

An advanced herbicide course is once again being given at the Forest Pest Management Institute in Sault Ste Marie in the latter part of September. The two week course addresses areas including basic/ forest herbicides, application technology, vegetation management, environmental impact and program management. Time is spent on the use of FSCBG as a planning tool for addressing the various options/ consequences of different spray strategies.

In Canada, we continue to pursue the integration of on board logging of spray events with the prediction capabilities of models for deposit and off target drift. Over the past few years, a monitor has been developed to log aircraft height, flows, atomizer rpm, boom pressure, aircraft track, ground speed and meteorology (RH, Ta) at on second intervals during the spray program. Presently, these parameters are being combined with tower winds in FSCBG to model the potential deposit within the target area. Ultimately, it is felt that the combination of these two systems will allow the operator to quickly evaluate his spray program for the need to respray.

This past November, the National Research Council, Forest Pest Management Institute and Environment Canada collaborated on a field trial to quantify the differences in the deposit and drift from the upwind and down wind wings of a spray aircraft. The study took place at the Jornada test site with support from the NMSU. Using a dual tank Cessna 188 aircraft, the deposit (ground plates) and drift (using balloon borne rotorod samplers) were quantified out to distances of 600m down wind of the spray line. The results clearly demonstrated the selective destruction of the down wind vortex when spraying in a cross wind, and hence the enhanced deposition from the upwind wing. Over the 9 spray trials, the integrated deposit out to 200m from the upwind wing was on average 1.5 times greater than the deposit from the down wind wing.

Recommendations for Enhancements to FSCBG

1) I think that the time has come to take the model one step closer to being used as a tool to assist an aerial applicator in evaluating his operational spray. The spray industry is moving to GPS guidance systems for aerial applicators and coupled with on board logging of relevant spray parameters, the data could be used as input to FSCBG for an evaluation of deposit to and drift from the spray block. Inputs from the Aircraft Spray Monitor would include lat/long, ground speed, aircraft height, flow rate, meteorology (RH, Ta), boom pressure and rotary atomizer rpm. From this could be calculated emission spectrum, release height, air speed, application rate (line source strength) and coupled with tower winds, the meteorology could be set. The model would have to consider each line as an independent spray since all of the above parameters would vary from spray line to spray line. Hence the model would automatically sum the results from the independent sprays. In this way, one would not have to worry about non parallel spray lines since the model can already handle non parallel lines if the model runs are carried out independently. At the meeting, a brief discussion covered the aspects of a different numerical approach to FSCBG, ie multi puff model to represent a line source. This method would be preferable as it would allow for variation of release parameters (ie. aircraft height, spray line not straight, flow rate, etc. presently measured every second along the spray line) along the spray line.

Recommend: Allowance for direct data input to FSCBG from Aircraft Spray Monitors with FSCBG being capable of modeling each spray line separately and then summing results.

2) Many spray scenarios include discrete differences in receptors over the area of interest. Example would be a herbicide application to a site for conifer release or site prep with a tree buffer surrounding the site and a water body adjacent to the buffer zone. Often times the deposit to the water is of interest in assessing environmental impact. Question: What effect does the tree buffer have on filtering out the drift cloud?? Recommend: Canopy characterization allow for discrete changes in canopy type at least along the downwind axis and possibly in the cross wind axis.

3)Recent studies have shown that there is sufficient difference in the lifetimes of the two vortices when spraying in cross winds to significantly influence the deposit/ drift from the two wings. Recommend: Reassess the lifetimes of the two vortices in cross wind scenarios so that an empirical relationship can be developed to modify the destruction of the vortices used in FSCBG.

4) Bob Sanderson has a good idea with regards to the Hint Book. Based on Milt's sensitivity studies,
Recommend: that the Hint Book indicate the accuracy to which the various input parameters must be measured in order to be able to attempt a comparison between field and model results.

Terry Biery
U.S. Air Force Reserve

Report by <u>Dr. Terry L. Biery</u>, Lt Col USAFR

23 June 1993

1. The specific model improvements were in the DoD pest management community are interested in include:

   a. Having the model accommodate more nozzle sites. This became important to us when we tried to run the model for our oil dispersant work. I understand that this has been accomplished or soon will be accomplished.

   b. We still want to validate the model's capability to tell us the amount or dosage of a spray that passes through a given space in a designated period of time. This is important for our mosquito control work. For Desert Storm preparation we ran the model to determine that a 3 mile swath width was feasible. We did this by backing in data from field trials conducted three years earlier.

   c. We still would like to make the model easier to run to make go or no go aerial spray operational decisions.

2. In November 1992, I gave a presentation at the DoD Armed Forces Pest Management Board Meeting on the advantages and disadvantage of models that could be used for pesticide dispersal to include the FSCBG and the AGDISP.

3. Jack asked me to mention that we have completed 2 extensive cooperative field tests on our C-130 modular aerial spray system's capability to apply oil dispersants. The first test was conducted at Crosbyton, Texas in November 1992 and the second test was conducted in March 1993 at Alpine, Texas. We started these tests in response to a U.S. Coast Guard's inquiry to the U.S. Air Force. Dr. Fred Bouse's group at Texas A&M has been involved with these tests. Multiple samplers were used and their effectiveness compared.

4. Each year we teach the DoD Aerial Pesticide Dispersal Certification Course. This course has been approved by EPA for certification in Category 11, Aerial Application. The USDA APHIS has developed a Memorandum of Understanding with DoD whereby they will send their personnel to our course to qualify their personnel for certification. The next course will be held 18-22 October 1993 at Youngstown ARS, OH. In the past we have had participation and assistance from Jack Barry, Milt Teske and Al Womac. Try to incorporate as much technology transfer information as we can into the course to include a section on the FSCBG.

If anyone is interested in our oil dispersant testing or our DoD Aerial Pesticide Dispersal Certification Course, see me during a break.

24 June 93

Terry Biery's Recommendation for FSCBG 5-Year Plan

1. Develop a technology transfer plan of the FSCBG model for the aerial spray applicator community with an emphasis on minimizing off-target drift and environmental impact.

2. Need to know where we actually flew in order to use the model for after-the-fact determination of spray deposition.

Group is a unique forum of experts that doesn't seem to exist anywhere else ie: entomologist, weather experts, engineers, spray technologists, researchers, operators, pest management experts.

APPENDIX C
1992 Recommendations

United States Department of Agriculture | Forest Service | Washington Office | 2121 C Second Street Davis, CA 95616

Reply To: 3400

Date: September 2, 1992

Subject: Technology Development Needs (Pesticide Application)

To: Director, FPM
Thru: Assistant Director, PUM&C

The National Spray Model Advisory Committee met at Charlotte, NC, June 20, to identify needs related to pesticide application and spray models. Technology needs listed below are included in FPM (Davis) Report 92-10, July 1992, Third Report - National Spray Model Advisory Committee.

Priority 1

.Conduct field tests to evaluate FSCBG under predictions in the near field.

.Develop a code for FSCBG to predict deposition and impaction on target foliage, and drift from air blast sprayers and other ground sprayers.

Priority 2

Enhance FSCBG for total accountancy of pesticide sprays and interface with environmental fate and impact models.

Priority 3

Evaluate natural and artificial samplers for use in quantitating spray deposition and drift. The three types of samplers of primary interest are impaction (flux), deposition, and air concentration (dosage). Collection efficiencies are needed for the samplers along with comparisons to similar samplers of known collection efficiencies.

Priority 4

Accelerate development of atomization model that uses existing data-bases, physical properties, and constants to predict atomization.

Priority 5

Evaluate the revised VALMET model connect to FSCBG and AGDISP with existing or new field data sets.

Priority 6

Evaluate the significance of drops <33 um in diameter to deposition and drift predictions of FSCBG using existing data bases, and recommend field testing if needed to fill data needs.

Priority 7

Improve deposit/witness card spread factor technology and develop method of determining spread factors in the field. This is needed by those who want drop size and spray volume/mass data for model evaluation and calibration.

John W. Barry

JOHN W. BARRY
Chairperson

cc: Mel Weiss, WO/FPM